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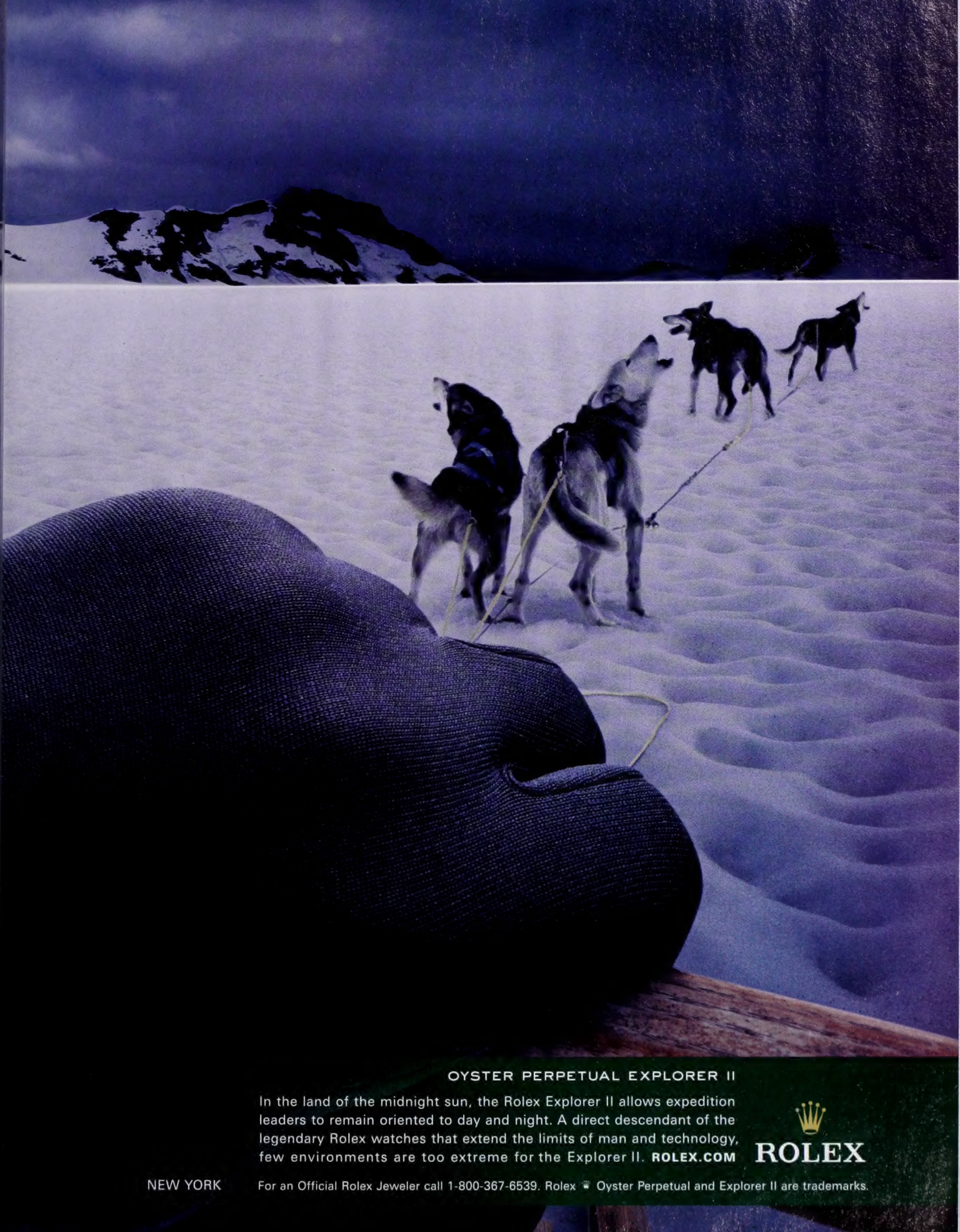

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[1] *UNAIDS Global Epidemic Update, 2003.*

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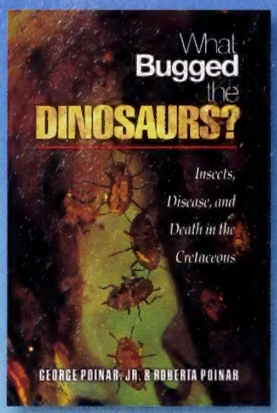

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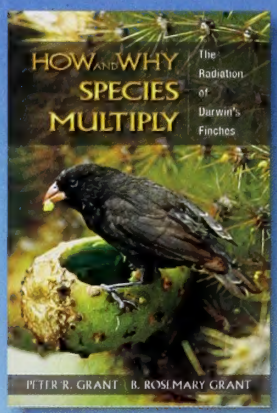

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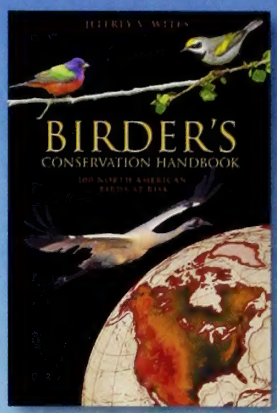

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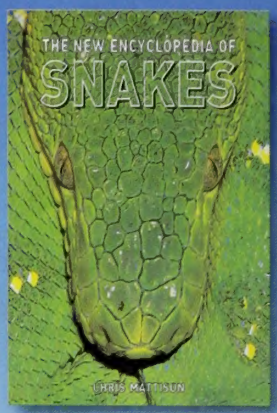

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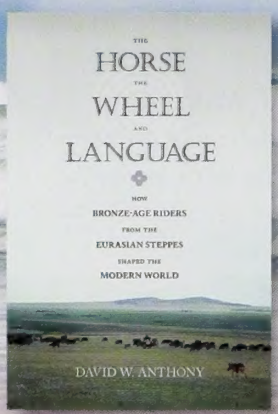
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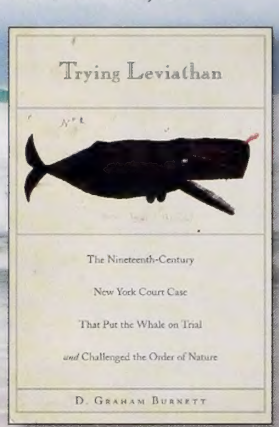
Trying Leviathan
The Nineteenth-Century New York Court Case That Put the Whale on Trial and Challenged the Order of Nature
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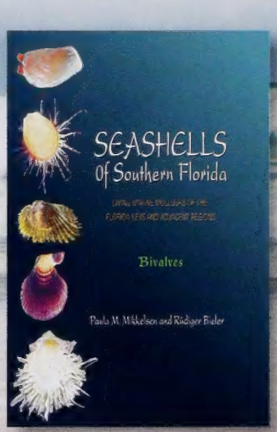

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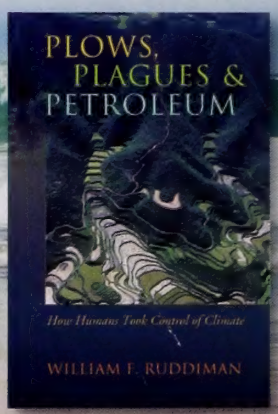

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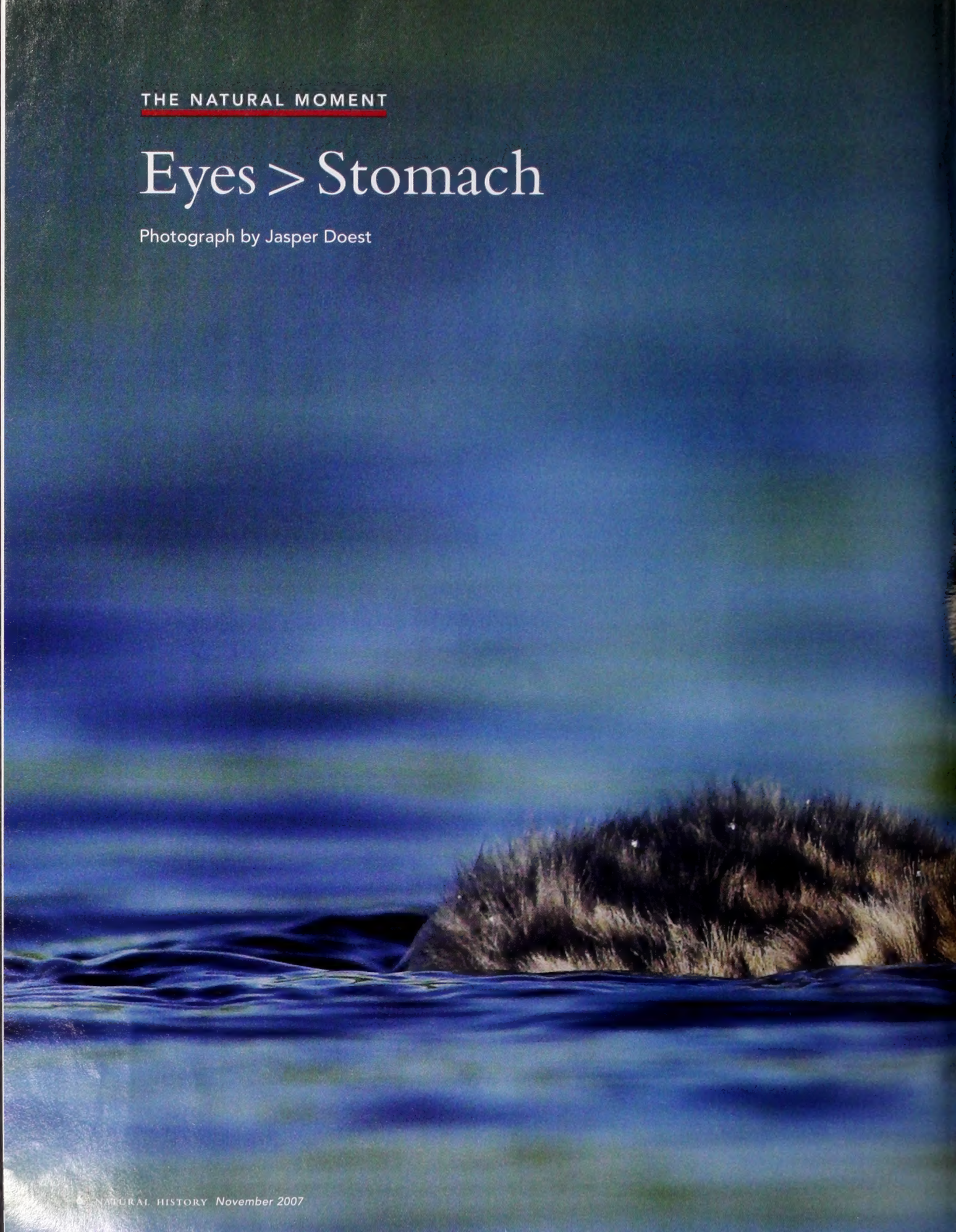
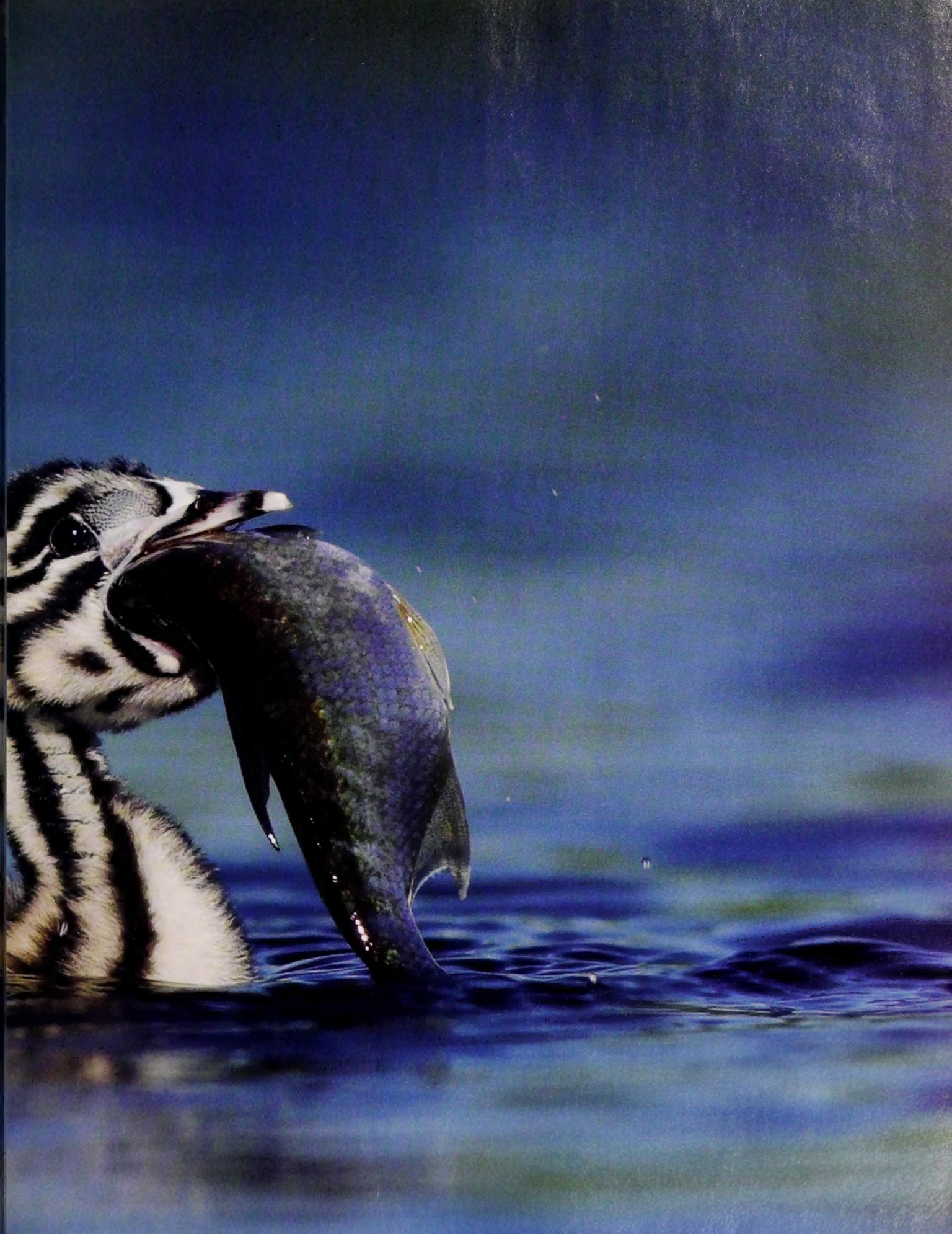
THE NATURAL MOMENT

Eyes > Stomach

Photograph by Jasper Doest





◄ *See preceding two pages*

Too much of a good thing can be overwhelming—raw fish, supersize meals, even water. An overabundance of the latter has beleaguered the Netherlands for a millennium. The Dutch have struggled to control fifty-four rivers with dikes, levees, pumps, windmills, and more, all the while waging a never-ending battle with the North Sea. In the past fifty years the country has spent more than $15 billion upgrading flood-control systems (which engineers in New Orleans are now studying).

Yet all that water is also one of the country's greatest resources—and among the many benefits, it attracts more than 350 species of birds. Photographer Jasper Doest spent two months near his home in Vlaardingen, in southwestern Holland, watching a mated pair of freshwater diving birds known as great crested grebes grow to a family of six.

Every morning and every evening Doest pulled on his waders before easing into a shallow canal to watch the grebes. He documented their courtship, nest building, egg laying, and, finally, their parenting of four zebra-striped chicks. Near the end of his stint, Doest caught the two-week-old chick pictured here mid-meal. The fish in its gullet, a bream served up by one of the parents, had been duly offered to the other chicks. But try as they might, none of them could swallow the wriggling fish—too much of a good thing for them to choke down. Finally one of the parents retrieved the catch and swallowed it in one gulp. —*Erin Espelie*

Seeking Fresh Waters

Maybe my questions are naive, "dumb," or impertinent, but my job as a journalist is to ask them. How, I wonder, can the world be plagued with a worsening water crisis? After all, at least in the developed world, sophisticated water treatment brings sweet water out of the tap. And if water is treatable, doesn't that make it a fully renewable resource? So what's all the fuss about? I take up my questions with Eleanor J. Sterling, the director of the Center for Biodiversity and Conservation at the American Museum of Natural History in New York, who introduces this single-topic issue on freshwater resources ("Blue Planet Blues," page 29); who writes, with Merry D. Camhi, about biodiversity in freshwater ecosystems ("Sold Down the River," page 40); and who, not incidentally, is the curator of a new exhibition, "Water: H_2O = Life," which opens at the American Museum on November 3.

As an educator and curator as well as an expert, Sterling understands where I'm coming from. "It's true," she replies, "water doesn't disappear from the surface of the earth. But what we're doing to it is moving it from underground into surface- or ocean-water systems, and not replenishing it in the areas where it started. We're also moving it from one river basin into another, and in the process, moving organisms that may have a heavy impact on the new system."

Does that mean there are freshwater ecosystems that should be set aside as natural areas? "I think there are," she tells me, but it ought to be done on a case-by-case basis. "There's the Pantanal [a region of marshland in southwestern Brazil], the Congo River [in west-central Africa], the Okavango delta [in Botswana]"—areas that need to be maintained for their "incredible diversity of human populations as well as wildlife." Other systems—the Florida Everglades come to mind—have already been badly damaged. "But the great thing about freshwater systems is that, while they're quick to react if we start to damage them, they are also often quick to revive."

To listen to an audio recording of my interview with Sterling, go to our Web site (www.naturalhistorymag.com); you'll find the audio link on our home page.

• • •

Many times in the past five years as the editor of this magazine, I've enjoyed working with curators, writers, and scholars such as Sterling, who speak knowledgeably and passionately about their expertise. At times, I've envied the depth of their specialized knowledge. But I've also thrilled to the rich variety of topics that editing this magazine has continually given me license to sample.

Still, life is short, and I've concluded it's time to move on, to rebalance the trade-off between depth and survey that I've lived with for the past five years. Beginning with the next issue, my friend and colleague Vittorio Maestro will take over as editor of *Natural History*. Vittorio knows as much about this magazine as anyone else alive, having spent almost thirty years on the staff. He, too, has the magazine editor's fascination with variety, and he'll bring his own fresh perspective on the natural world that *Natural History* has covered for 107 years. I think you'll like what he brews up. —Peter Brown

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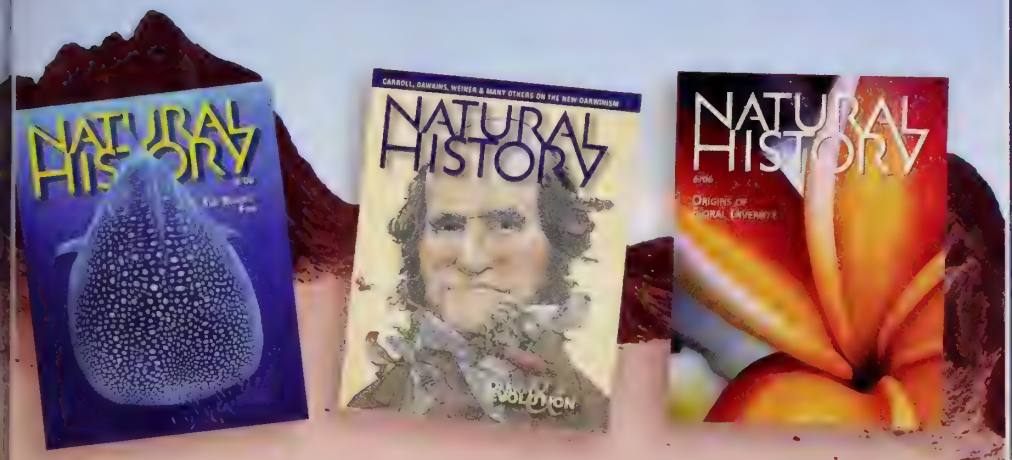

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Top row, left to right: Doest, Sterling, Mundy, Kathmann
Middle row, left to right: Schenter, Camhi, Nappier, Lawrence
Bottom row, left to right: Schwab, Penland, Alwash, Postel

Wildlife photographer **JASPER DOEST** ("The Natural Moment," p. 6) often travels to foreign lands—Helgoland, Lapland, Poland—in search of interesting animal subjects. But for the baby grebe pictured in this issue, Doest stayed in his homeland, the Netherlands. See www.doest-photography.com to enjoy more of his images.

After twenty-five years of far-ranging fieldwork, **ELEANOR J. STERLING** ("Blue Planet Blues," p. 29 and "Sold Down the River," p. 40) knows the full spectrum of Earth's waterways well—a knowledge she amply poured, as curator, into the latest exhibit at the American Museum of Natural History, entitled "Water: H_2O = Life." Her expertise on one particular river, the Mekong, shaped her coauthorship of the book *Vietnam: A Natural History*. She currently directs the Center for Biodiversity and Conservation at AMNH and teaches at Columbia University in New York.

CHRISTOPHER J. MUNDY, SHAWN M. KATHMANN, & GREGORY K. SCHENTER ("A Special Brew," p. 32) study chemical physics at the Pacific Northwest National Laboratory in Richland, Washington. Although diverse in their respective areas of expertise, the trio shares a common bond: a fascination with the elusive nature of water. Mundy, who trained as a theoretical chemist, creates computer models of H_2O. Kathmann, a physicist, developed a molecular theory for how water condenses, crystallizes, bubbles, and more. Schenter—also a physicist—has studied the chemical reactions of water on a quantum scale. Due to their collaborative efforts, water is less mysterious on the micro level.

Waters, according to **MERRY D. CAMHI** ("Sold Down the River" p. 40), have coursed through her entire life: from the chance meeting of her future husband on the mudflats of Shark River in New Jersey to her graduate work on sea turtles to editing *Sharks of the Open Ocean* (Wiley-Blackwell, 2008). She serves as the content coordinator of AMNH's exhibit on water.

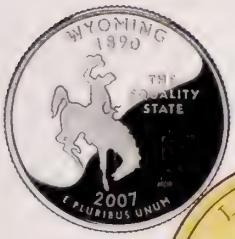
SHARON P. NAPPIER, ROBERT S. LAWRENCE, & KELLOGG J. SCHWAB ("Dangerous Waters," p. 46) coordinated their efforts at the Johns Hopkins Bloomberg School of Public Health (JHBSPH) in Baltimore, Maryland in order to highlight some of the imminent dangers to the cleanliness of the world's dwindling freshwater supplies. Lawrence is the founding director of the Center for a Livable Future at JHBSPH. Schwab, director of the Center for Water and Health at JHBSPH, is currently trying to improve methods of detecting noroviruses. He and Nappier, a graduate student in his laboratory, are also studying those and other pathogens in non-native oyster species found throughout the Chesapeake Bay.

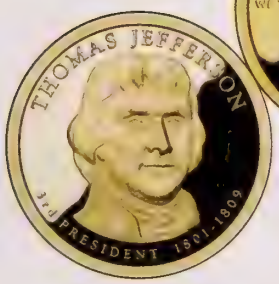
SHEA PENLAND ("When the Seas Come Marching In," p. 50) addresses the current state of affairs in the Mississippi Delta region and reconsiders the prophetic article he wrote for *Natural History* in February 2005. He is the Director of the Pontchartrain Institute for Environmental Sciences at the University of New Orleans, and the University's Braunstein Professor of Petroleum Geology.

As soon as Saddam Hussein was removed from power, **AZZAM ALWASH** ("Water at War," p. 56) quit his job as a geologic engineer in California and changed course: he set his sights on restoring the marshlands of Iraq. He continues to make headway on improving the wetlands' health with the Eden Again Project (www.edenagain.org).

SANDRA L. POSTEL ("Sharing the River Out of Eden," p. 60) examines the world through the lens of water—namely, how would the world look without it? Food security, environmental health, and international relations are a few of the touchstones Postel covers here and in her three books. She runs the Global Water Policy Project, geared toward sustaining the Connecticut River watershed, and directs the Center for the Environment at Mount Holyoke College in South Hadley, Massachusetts.

We don't mean to brag.
But come on. Look at them.





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The Deep Roots of Altruism

Joan E. Strassmann and David C. Queller's article "Altruism among Amoebas" [9/07] provides a fascinating account of the operation of altruism in both social amoebas and the human "dicty community." But I have a reservation: in paragraph two we are told that we should expect to find the roots of human altruism "deeper in nature"; in the penultimate paragraph, which returns to humans, we learn that human cooperation "often depends on reciprocation." Embedded within a discussion of specific genetic mechanisms, these statements may leave the impression that the mechanisms described in the article apply to us to some degree. Although human altruism likely has a genetic basis, I am reasonably confident that the mechanism(s) does not involve the *dimA* or *csaA* genes. Because of this, *Dictyostelium discoideum* has no direct bearing on the "roots" of our own version of altruism. The research on amoebas supports the idea that altruism in humans has a genetic basis. However, the support is analogical, not functional.

James J. Moore
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University of California, San Diego
La Jolla, California

DAVID C. QUELLER REPLIES: We agree that human altruism is unlikely to involve the same genes that we study in social amoebas. Indeed, many of those genes are absent from the human genome. We are trying to understand the general principles by which social genes evolve, principles that may eventually be shown to operate in humans. For example, it is likely that kin selection is involved in human altruism. We would be surprised if the insight from *dimA*—that social genes can reduce cheating by piggybacking on other essential functions—does not apply to other genes in other species. The human genome might include so-called greenbeard genes—which enable altruism toward others who carry them—now that they have moved from hypothesis to reality, as in the case of *csaA*.

Dark Matters

I was intrigued by Donald Goldsmith's article "Dark Matter" [9/07], as I have been by all I have read on dark matter and dark energy. While I am not a physicist or a cosmologist, I can't help but wonder if there might not be yet another explanation for this extraordinary finding. We ask what there was before the big bang. Is it not possible that this non-

baryonic material was the medium in which the big bang occurred, and that it is a part of the fabric of a universe that preceded the one we know?
David Shander
Denver, Colorado

I wish that astronomical articles in *Natural History* paid less attention to exceptionally speculative issues like dark matter. By way of contrast to Donald Goldsmith's article, see "Modern Cosmology: Science or Folktale?" in the September/October issue of *American Scientist*. If anyone wonders why the American public is weary of funding these games, that article would be a good place to begin looking for an answer. I suspect that there is a growing confusion in the scientific community about the ontological status of mathematics. Nothing in mathematics is real. There are often interesting and useful connections with the real world, but extending mathematical formalisms too far beyond experimental verification is simply abuse of a useful tool.
Dwight Brown
Kerrville, Texas

DONALD GOLDSMITH REPLIES: I attempted to explain the chain of reasoning that leads most astrophysicists to conclude that dark matter predominates over visible matter in the universe. Those astrophysicists recognize that their conclusion rests on certain assumptions and might be overturned, but current data suggest that dark matter is the most reasonable way to explain such matters as the observed motions of galaxies in galaxy clusters and the abundance of cosmic nuclei.

The question of what existed before the big bang remains largely unresolved, though the most widely accepted answer among cosmologists is that nothing existed, not even space or time. Dark energy deserves an article by itself [*see "Gravity in Reverse," by Neil deGrasse Tyson, 12/03–1/04*]. As with dark matter, the conclusion that dark energy provides most of the energy in the universe seems well established, while remaining subject to disproof by further observations and better interpretation of the existing data.

Natural History *welcomes correspondence from readers. Letters should be sent via e-mail to* nhmag@naturalhistorymag.com *or by fax to 646-356-6511. All letters should include a daytime telephone number, and all letters may be edited for length and clarity.*

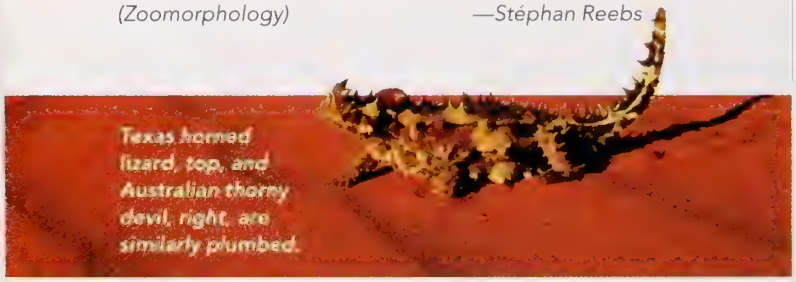
plishsplash
It is what makes people, places and things squeaky clean and springtime fresh. It is chemistry.

Animal Aqueduct

Cuddly they're not, but the Texas horned lizard and the Australian thorny devil share more than just prickles. They boast the same remarkable adaptation to their arid homelands: scale-covered skin that captures water and carries it to the animal's mouth, enabling it to drink when raindrops hit its back or even, in the thorny devil's case, when its belly meets damp sand. Recently, a team led by Wade C. Sherbrooke of the American Museum of Natural History in New York figured out how this weird plumbing system works.

Using advanced microscopy, the investigators discovered minute ducts beneath the base of the skin scales. The hair-fine ducts connect to form a network that covers the lizard's body and opens up in the corner of the mouth. Sherbrooke and his colleagues think that water, pulled by capillary action, slips under the scales and spreads through the interconnected ducts. The animal, apparently by moving its tongue and jaws in a particular way, can draw the water into its mouth and take a sip.

As their names suggest, the Australian thorny devil and the Texas horned lizard live on opposite sides of the world and are not closely related, and so the water-transporting skin that cloaks both species is a striking example of convergent evolution. *(Zoomorphology)* —*Stéphan Reebs*



Texas horned lizard, top, and Australian thorny devil, right, are similarly plumbed.

A Grave Mistake

Dragonflies congregate at a cemetery in the Hungarian town of Kiskunhalas, perching on twigs and iron railings near polished black tombstones. It seems the insects mistake the horizontal surfaces of the stones for water, say Gábor Horváth of Eötvös University in Budapest and colleagues.

Still water usually reflects polarized light in a specific pattern, and some water-loving insects use the pattern to locate puddles and ponds. As Horváth's team discovered, reflections from horizontally oriented, polished black gravestones create the same pattern as water does. In several tests at the cemetery, the dragonflies—all members of the genus *Sympetrum*—showed no interest in matte dark objects or in polished light-colored stones, neither of which reflect polarized light in just the right way.

Dragonflies mate near water and lay their eggs in it. Horváth's team observed males and females at the cemetery flying in tandem over the black stones, sometimes touching them as if to deposit eggs. The researchers found no eggs on the graves, but the possibility remains that gravestones—and other dark, shiny horizontal surfaces where dragonflies sometimes gather, such as pools of oil and spiffy cars—can act as "ecological traps" for insects attracted to certain patterns of polarized light. *(Freshwater Biology)* —*S.R.*

Sympetrum dragonfly perches in a Hungarian cemetery.

When Life Gives You Lemmings

In a good summer, an Arctic fox living near a goose colony on the Canadian tundra can steal as many as 2,000 eggs. Foxes bury most of their loot for future consumption, and they don't bother to stamp an expiration date on it. A year later the eggs are still edible, a new study shows.

During four consecutive springs, just before snow geese arrived on the tundra to breed, Gustaf Samelius, then a graduate student, and three colleagues at the University of Saskatchewan in Saskatoon collected blood from wild foxes. By analyzing the proportions of the isotopes carbon-13 and nitrogen-15 in the blood samples, the team established that goose eggs were an important part of the foxes' diet even eleven months after being cached by the carnivores. Freezing undoubtedly preserves the eggs through the winter; in the fall and spring, rot-causing bacteria seem to be inhibited in intact eggs by the shell and membrane and by protective proteins in the white.

The researchers also discovered that in years when collared lemmings were abundant, the foxes ate fewer eggs. Cached eggs, it seems, are merely a standby in case the foxes' preferred food—lemming—is in short supply. *(Journal of Animal Ecology)* —*S.R.*

Arctic fox snatches an egg from a goose nest.

Ancient bee, trapped in amber, bears a load of orchid pollen.

California ground squirrel confronts a rattlesnake by flagging its tail in warning.

One for the Record

When the poet William Cullen Bryant wrote that the "loveliest of lovely things are they on Earth that soonest pass away," he could easily have been describing orchids. Although experts agree that they've brightened the planet for millions of years and now number well over 20,000 species, the ephemeral plants have never appeared in the fossil record . . . until now.

An ancient stingless bee was found trapped in a piece of amber 15 to 20 million years old, with a precious few packets of orchid pollen clamped to its back. That singular plant-and-pollinator duo enabled Santiago R. Ramirez, a graduate student at Harvard University, and several colleagues to make previously impossible determinations about orchid evolution.

On the basis of the shape and packaging of the pollen grains, Ramirez positioned the orchid—*Meliorchis caribea*, a species new to science—on a phylogenetic tree. He then calibrated the tree with existing molecular data from the rest of the orchid family. Orchids, he found, started diversifying about 65.5 million years ago, from a common ancestor that probably arose some 80 million years ago. That means the original lovelies may have bloomed alongside the dinosaurs—much earlier than most orchid biologists had thought. *(Nature)*

—Erin Espelie

Tell Tail

Coping with rattlesnakes is a fact of life for California ground squirrels. Fortunately, adult squirrels are immune to the snake's venom. To protect their susceptible pups, when a rattler comes near they sound an alarm, then fling pebbles and sand at the predator. Now, a team at the University of California, Davis has discovered a previously unknown means of communication in the squirrels' defensive arsenal: they warm up their tails to tell the heat-sensitive vipers they mean business.

Biologists have long observed squirrels flagging their tails in the air when threatened by rattlesnakes or gopher snakes. By pointing an infrared camera at the squirrels, Aaron S. Rundus and his team discovered that the squirrels' tails were several degrees hotter than normal while waving at rattlesnakes, which have specialized heat detectors, but not while waving at gopher snakes, which lack such detectors. The thermal signal, the authors posit, is meant for rattlesnakes.

To test whether rattlesnakes actually pay attention to the warning, Rundus's team designed a robotic squirrel with a temperature-controlled tail. Indeed, when the tail warmed up, rattlesnakes slithered away, apparently discouraged to learn that the "squirrel" had spotted them, foiling a surprise attack. The squirrels' use of heat to get their message across is a first in the animal kingdom. *(PNAS)*

—Brendan Borrell

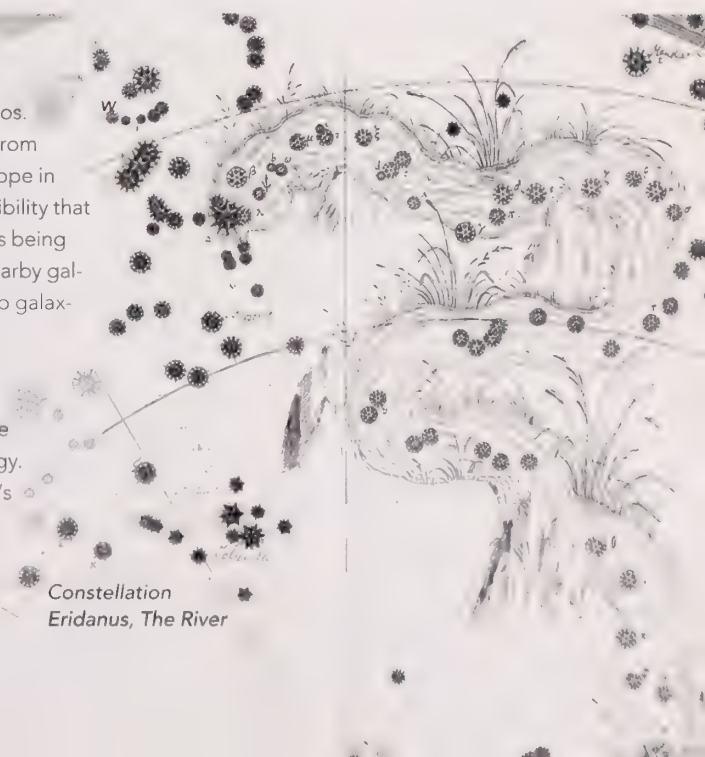
Nothing Much

News flash: astronomers think they've discovered a whole lot of nothing. In the constellation Eridanus, near Orion, some 10 billion light-years from Earth, there appears to be a vast expanse of empty space, completely devoid of matter—no stars, no planets, no black holes, no gases, not even any dark matter. It's almost a billion light-years across, more than sixty times larger than any previously known cosmic void.

The void's discoverers—Lawrence Rudnick of the University of Minnesota, his collaborator Liliya R. Williams, and his graduate student Shea Brown—already knew the region was unusual because cosmic microwave background radiation (ubiquitous faint radio waves left over from the big bang) appears much weaker there than elsewhere in the cosmos. Then the team's analysis of data from the Very Large Array radio telescope in New Mexico eliminated the possibility that the region's microwave signal was being obscured by radio waves from nearby galaxies: there are just too few "radio galaxies" in the vicinity to do the job.

The remaining possibility was empty space, which could also weaken the signal—thanks to the effect of omnipresent dark energy. Rudnick's calculation of the void's colossal size is based on the apparent weakness of the radiation. *(Astrophysical Journal)*

—S.R.



Constellation Eridanus, The River

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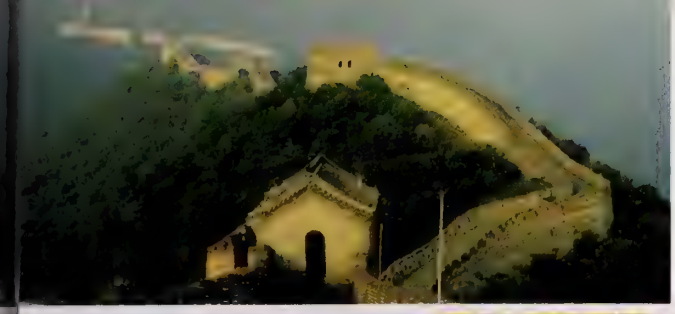

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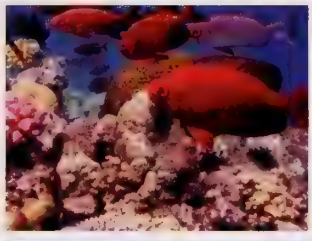


Losing Contact

Agriculture, development, and logging are often blamed for habitat fragmentation. Now we can blame global warming, too. Worldwide, a combination of rising temperatures and fire suppression by foresters is causing mountain tree lines to climb. The trees are creeping into alpine meadows and carving them to pieces; along the way, animal populations are being carved up as well.

Take Jumpingpound Ridge in the Rocky Mountains of Alberta. There, trees now live some 650 feet higher up the mountainsides than they did forty years ago. Each year from 1995 through 2005, Jens Roland of the University of Alberta in Edmonton and Stephen F. Matter of the University of Cincinnati surveyed the number of Apollo butterflies, *Parnassius smintheus*, living in a series of alpine meadows on the ridge. After counting each meadow's butterflies for eleven summers and comparing the fluctuations in their numbers, Roland and Matter discovered that the broader the swath of forest between two adjacent meadows, the less in synch were the ups and downs of the two butterfly populations. In other words, populations divided by thick forest fall out of touch and become increasingly independent.

The encroaching forests, the ecologists conclude, prevent the Apollos (and quite possibly other organisms) from dispersing and thus mixing their genes. That could be bad news for the butterflies and other locals: isolated populations are more vulnerable to being wiped out than are connected populations. *(PNAS)* —*S.R.*

Apollo butterfly basks in a Rocky Mountain meadow.

Bias or Balance?

Scientific consensus that humans have caused global warming coalesced in about 1995. Yet for the next decade many Americans still believed that humankind's role in the emerging crisis was a matter of great debate. A new study lays some of the blame for that national misconception on the nightly TV news shows. To avoid the appearance of bias, they continued to air contrarian viewpoints long after the scientific debate was settled.

Maxwell T. Boykoff of the University of Oxford analyzed 143 news segments about climate change that were broadcast between 1995 and 2004 on programs ranging from the *CBS Evening News* to CNN's *Wolf Blitzer Reports*. Only 28 percent of the segments paralleled scientific opinion in portraying humans as the main cause of global warming, Boykoff discovered. Just a handful of segments went so far as to suggest that humans had a negligible effect on Earth's climate, but a full 70 percent gave roughly equal play to both sides of the debate.

Journalistic skepticism is useful, but Boykoff thinks that in this case, overrepresentation of minority opinions amplified uncertainty in viewers' minds. Fortunately, he notes, the accuracy of TV news—at least regarding humanity's role in global warming—has improved since 2004. *(Climatic Change)* —*B.B.*

Change on the Range

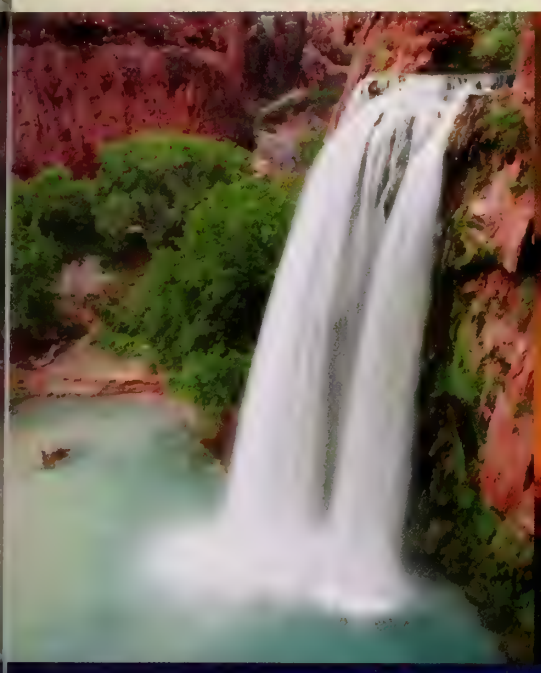
On rangelands around the world, grasses are giving way to woody shrubs. Deer and antelope still have room to play, but the encroaching shrubbery worries ranchers, who rely on grasses as forage for their cattle. As has long been suspected, the rising concentration of atmospheric carbon dioxide (CO_2) contributes to the proliferation of shrubs.

In a five-year experiment on Colorado's shortgrass steppe, Jack A. Morgan of the U.S. Department of Agriculture in Fort Collins, Colorado, and colleagues placed six clear-sided, open-topped enclosures on the ground before each growing season. Air circulated continuously through all six enclosures; three received natural air, and three received air with double the current atmospheric concentration of CO_2.

Inside the enclosures with double-strength CO_2, fringed sage (*Artemisia frigida*)—a small shrub unpalatable to cattle—flourished dramatically, while almost all forage grasses grew at their normal rates. Like many other rangeland shrubs, fringed sage absorbs more atmospheric carbon during photosynthesis than most grasses do. Morgan's team expects that shrubs worldwide are responding to elevated CO_2 in a similar fashion. Since atmospheric CO_2 may well double by 2100, the explosion of shrubbery in the experimental enclosures could occur on many open rangelands, with inestimable economic and ecological consequences. *(PNAS)* —*Harvey Leifert*

Cattle ponder grass futures on the Colorado range.

DISTINCTIVE *Destinations*



...Outer Banks Travel & Tourism Department

Arizona

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Offering stunning views of Sedona's red rocks, **The Gallery on Oak Creek** emphasizes not only the taste of food but also its presentation. In addition to a new menu and redesigned interiors, this restaurant features original art in a variety of media from local as well as national artists—both on the tabletops and the walls. Guests are given an "art menu" detailing the artwork in addition to the menu of eclectic cuisine and fine wines.

The Hualapai Lodge, on the western rim of the Grand Canyon, is a perfect base from which to embark on a range of activities, including whitewater rafting, helicopter tours, fishing, and hiking. In between, try the authentic Native American cuisine of **Diamond Creek Restaurant**, located at the Lodge. Specialties include the Hualapai taco and stew with Hualapai fry bread.

In Phoenix's Arcadia District, **Chelsea's Kitchen** showcases American-Southwest style cuisine and has earned praise from visitors as well as locals. Sit in the back patio, overlooking the Arizona Canal, and enjoy the casual atmosphere while sampling the local favorites of prime rib, roasted chicken, and green chile stew. With views of the spectacular Catalina Mountains, **Terra Cotta** is one of Tucson's most lauded

restaurants. Featuring innovative regional cuisine—a fusion of native Southwest and northern Mexican ingredients and contemporary French cooking—Terra Cotta is known for its complex and robust sauces. The atmosphere is relaxed, with an intimate outdoor area, and indigenous Southwest materials incorporated into the décor. Every twelve to eighteen months, Terra Cotta commissions a piece of artwork to use in its Wine Label Artists' Series. The artwork is displayed at the restaurant and reproduced as labels for the house wine collection, menu covers, postcards, promotional pieces, and brochures. The series provides an opportunity to promote Southwestern art and local artists.

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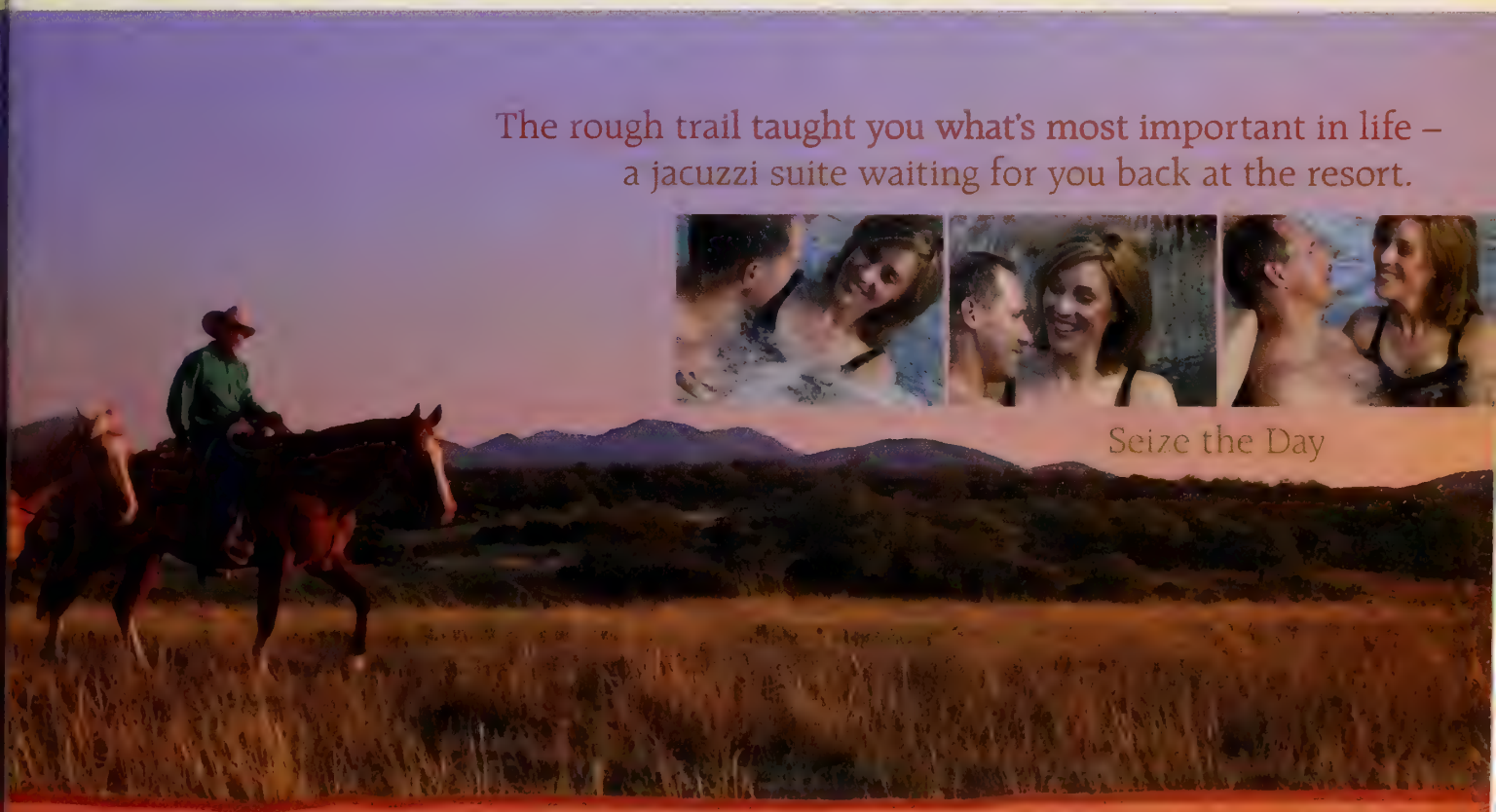

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GRAND CANYON STATE

Tucson

Just an hour away from Mexico, Tucson has a long history of settlement by ancient tribal peoples, Spanish explorers, and Anglo frontiersmen.

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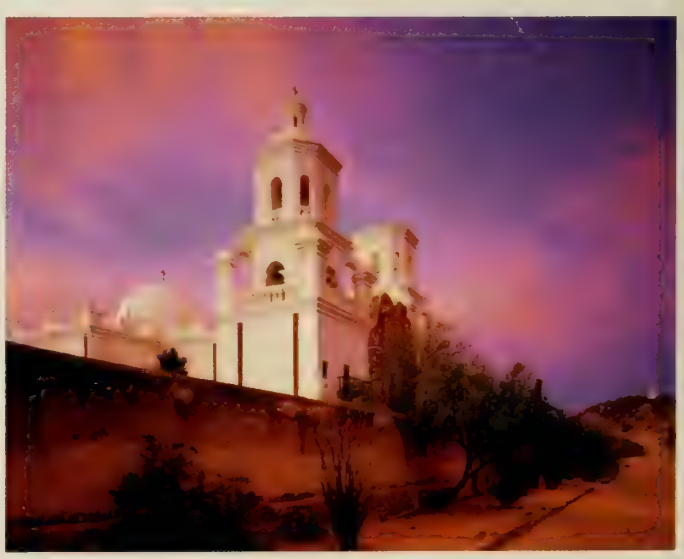
The blending of cultures is evident throughout Tucson. You'll see it at the Mission San Xavier del Bac, an outstanding example of Spanish Mission architecture that is located on the Tohono O'odham Indian Reservation. The Mission was founded by the Jesuit priest Father Kino in 1700, but many say the design and construction of the church may have been the work of the Tohono O'odham; fittingly, you can admire the Mission, then step outside to sample some Indian fry bread, dipped in honey. The shining white church, which combines Moorish, Byzantine, and late Mexican Renaissance elements so seamlessly it's hard to tell where one begins or ends, was built between 1783 and 1797. The Tohono O'odham, whose ancestors welcomed Father Kino to their village, are descendants of the Hohokam Culture, an ancient people of the Southwest. To learn more about the "Desert People," visit the Tohono O'odham Nation Cultural Center & Museum, which opened in June of this year in Topawa, the capital of the Tohono O'odham Nation. This $15.2 million state-of-the-art facility houses priceless artifacts, some dating back nearly 10,000 years. To showcase the Tohono O'odham's traditional life and history, the exhibits include ancient arrowheads, tools, and pottery as well as many works from the 1700s to the present, including modern paintings, photographs, baskets, and World War I memorabilia.

To learn more about Tucson's Spanish history, follow the Juan Bautista de Anza National Historic Trail, which commemorates the route followed in 1775–76 by a Spanish commander who led a party of colonists on an expedition from Mexico to found a presidio and mission near the San Francisco Bay. The trail takes you to Tubac Presidio, now a state park, and to Tumacacori National Historical Park, where you'll see the abandoned ruins of three Spanish colonial missions, including Tumacacori itself, which dates back to 1691.



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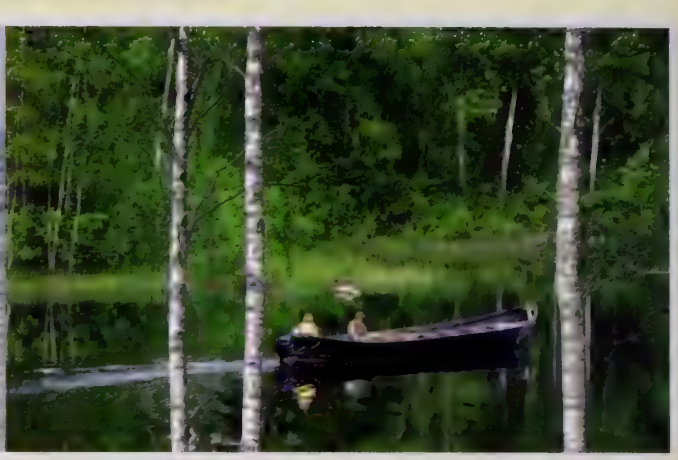

Karsten Bidstrup

FINLAND IS KNOWN AS THE LAND OF A THOUSAND LAKES, BUT IT ACTUALLY HAS even more: 187, 888 at the last count. The lakes are linked by a labyrinth of rivers, straits, canals, and inland waterways, creating many opportunities for outdoor recreation. In summer the lakes are full of boaters and swimmers, and in winter they are a mecca for skaters and skiers.

Almost 40 percent of the eastern part of the country is covered with water and is known as the Lake District or Lakeland. On the border with Russia, the Saimaa lakes, interconnecting waterways dotted with lovely small towns, are a haven for vacationers drawn to their beauty and peaceful environment. This is the perfect place for booking a lakeside cottage or farm holiday, taking a cycling tour, or hiking in the Linnansaari and Kolovesi national parks. Finland enjoys some of the most unspoiled natural environment in Europe, and it is on display in these two parks. Linnansaari, with over 130 islands and many lakes, is a typical Finnish landscape. Kolovesi National Park conserves the ecosystems of the inland archipelago of the Saimaa lakes and forests. Both parks protect the habitat of the Saimaa ringed seal. The Turku Region, in southwest Finland, is where the recorded history of Finland begins. Turku is not only Finland's oldest city but also its first capital. The Turku archipelago, in the Baltic Sea, was created by the Ice Age and is characterized by rocky islets, forested islands, and open sea.

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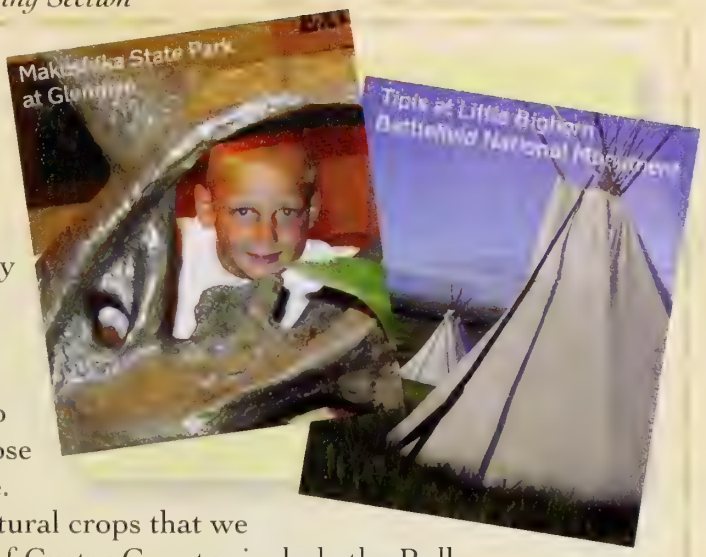

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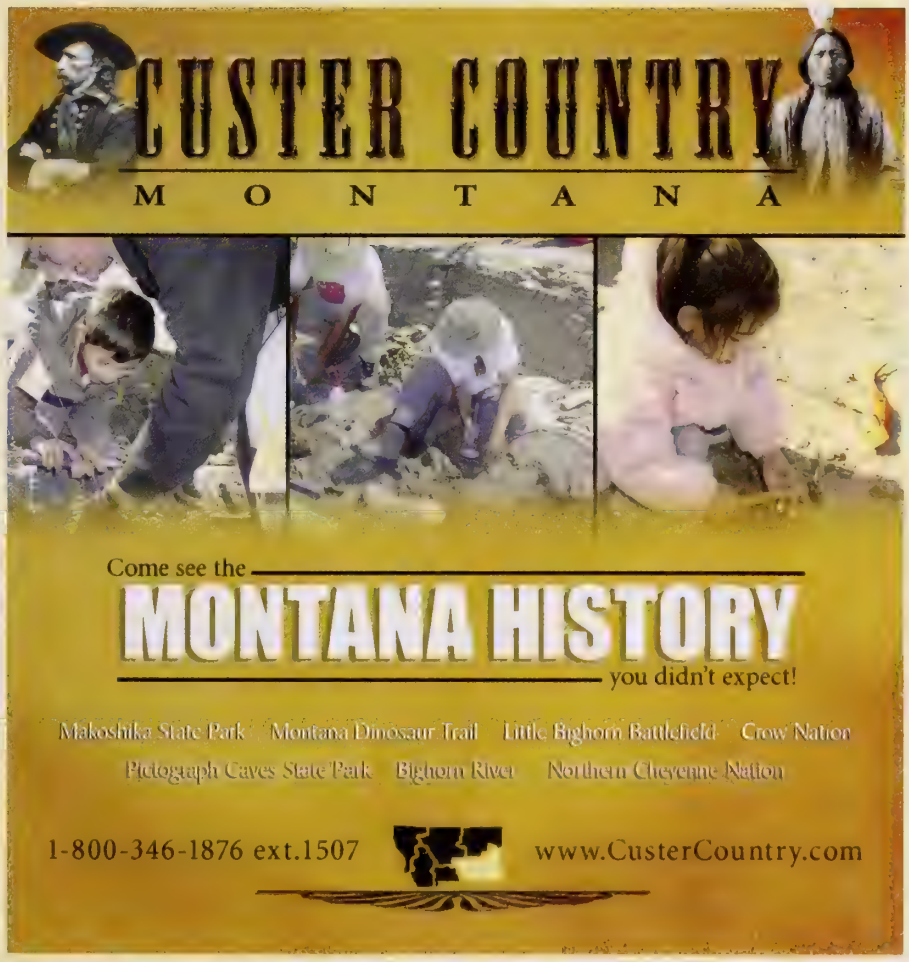


Currituck County
NORTH CAROLINA

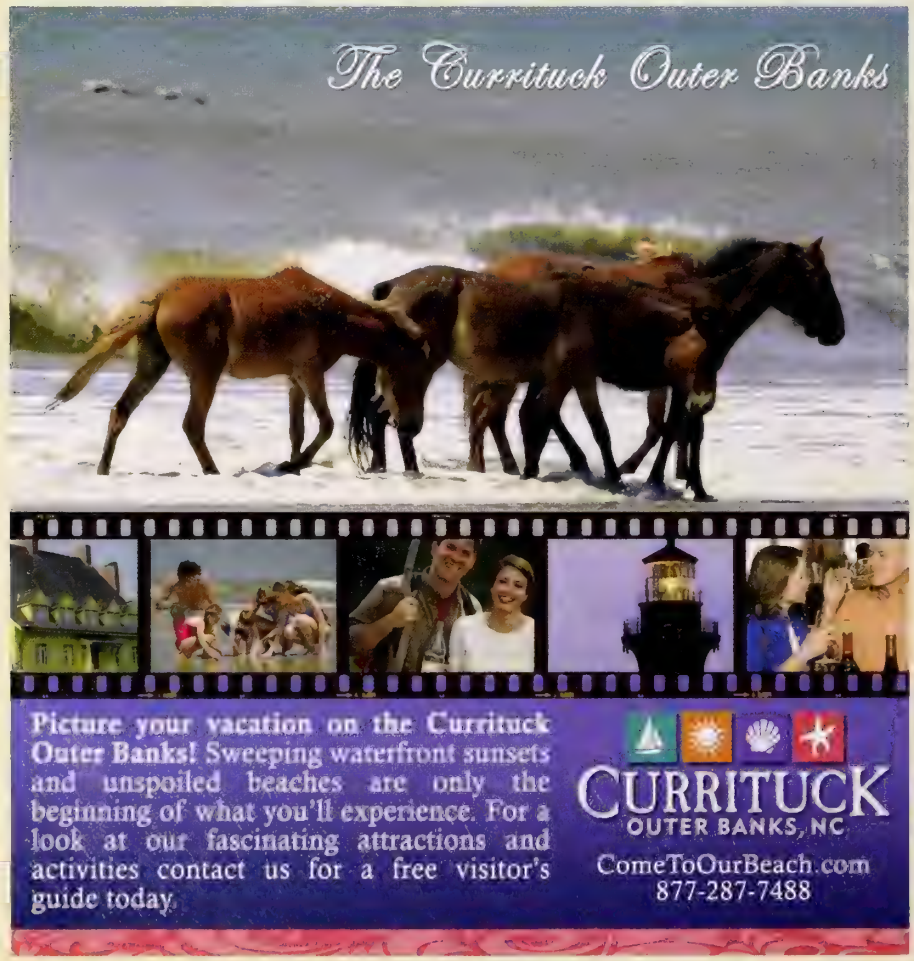
Photos: Currituck Outer Banks Travel & Tourism Department

CURRITUCK COUNTY, tucked in the northeastern corner of North Carolina, lies along the Outer Banks on a picturesque peninsula between Kitty Hawk and Chesapeake, Virginia. Bordered to the east by the Currituck Sound, the county is separated from the Atlantic Ocean by natural barrier islands and is known for its pristine beaches and historic attractions.

A visit to Currituck Heritage Park in Corolla transports you to life on the Outer Banks in the 1920s. Featured at the park is the Whalehead Club, originally an exclusive hunt club when built in 1925. The fully restored building is a popular attraction, along with a historically landmarked boathouse and footbridge. Nearby sits the Currituck Beach Lighthouse and light keeper's house. For over a century, the Lighthouse guided ships safely along the Chesapeake Bay to nearby ports. Climb to the top for spectacular water views and unforgettable sunsets.

The Outer Banks Center for Wildlife Education, also in the park, contains educational exhibits and conservation information. Currituck Sound is noted for its fish and waterfowl populations, as well as the migratory paths of ducks and Canada geese.

While in Currituck County, be sure to see the Corolla Wild Horses – Spanish mustangs that have roamed freely on the Currituck Outer Banks for 400 years.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water
the wellspring of life

A Special Report on the World's Freshwater

BLUE PLANET BLUES

Demand for freshwater threatens to outstrip supply. How can we meet the needs of all of Earth's species?

By Eleanor J. Sterling

Water: evolving life-forms crawled out of it hundreds of millions of years ago, yet it still envelops us in our fetal state, suffuses every tissue of our body, and surrounds our drifting continents. From ancient origin myths and ritual baths, to Handel's *Water Music* and the play of ornate fountains, to water parks and water slides, we celebrate it. Water molecules move through the years and across the globe, from rivulets to rivers to oceans, rising into the atmosphere and falling back to land, connecting each of us to the rest of the world. In this global cycle, each of us is always downstream from someone else.

Despite all the water in the world, only a small fraction is available to us and other species that depend on freshwater. Salty seas account for more than 97 percent of the water on Earth. Of the remaining 3 percent or so, at least two-thirds is tied up in glaciers, ice caps,

and permafrost, or else lies deep underground, of little use to those of us living on the land above.

This special single-topic issue of *Natural History* examines that last 1 percent, that precious supply that keeps us alive. The articles range from technical to fanciful. Christopher J. Mundy, Shawn M. Kathmann, and Gregory K. Schenter look at the properties of water, and how it plays its fundamental role in the planet's heat budget and weather systems. Dolly Setton's graphic depicts the many remarkable ways animals have adapted to limited water resources. Merry D. Camhi, who has assisted me in my role as curator of the exhibition "Water: H_2O = Life," which opens this month at the American Museum of Natural History, joins me in a look at why freshwater ecosystems are so vulnerable to declines in biodiversity. Sharon P. Nappier, Robert S. Lawrence, and Kellogg J. Schwab detail the worldwide human health concerns of contamination, pollution, and waterborne diseases. Shea Penland presciently outlined, in the February 2005 issue of *Natural History*, the threat to New Orleans from hurricanes and catastrophic flooding. Now, he gives a sobering appraisal of current "reconstruction" efforts. Chuck Carter's illustration depicts a range of creative high- and low-tech solutions to the challenges of limited or contaminated water supplies. Azzam Alwash describes the heartening recovery of marshlands in post-Saddam Iraq. And Sandra L. Postel explores the politics of water in the Middle East.

Freshwater is not evenly distributed across the globe. The Americas have the largest amount and Oceania (Australia, New Zealand, and the Pacific islands) the smallest. Thinly inhabited Oceania, however, has the greatest per capita supply, more than 9.5 million gallons per person per year. Asia has the lowest. By country, Brazil, Canada, China, Colombia, Indonesia, and Russia together have half the world's supply of freshwater; northern Africa and the Middle East are the water-poorest. The United Nations defines water scarcity as less than 500 cubic meters (132,000 gallons) per person per year. Kuwait has a natural supply only one-fiftieth that amount, but given its huge supply of oil, it can afford to run desalination plants.

At the individual level, further inequities emerge. Although a person can manage for a few days on a gallon or two a day, an adequate supply of clean water is about thirteen gallons per person per day. Ten percent of it is needed for drinking, the rest for sanitation and hygiene (40 percent), bathing (30 percent), and cooking (20 percent). In 2006 the UN estimated that more than a billion people—one-sixth of the world's population—lack even the bare minimum gallon-plus per day of safe drinking water, and 2.6 billion lack access to basic sanitation. In contrast, those of us who live in the United States and Canada each consume, on average, more than 150 gallons a day for domestic and municipal purposes (not including agricultural and industrial usage). In the United Kingdom people do fine with about a fifth as much.

People appropriate more than half the world's available surface freshwater. Globally, 70 percent of withdrawals from rivers and groundwater are used for agriculture, 22 percent for industry, and the remaining 8 percent for homes and municipal use. As demand increases, driven by both population growth and soaring consumption rates, water appropriation is projected to rise to 70 percent by 2025. In many ways, we are already damaging the systems that provide us with this critical natural resource.

One-sixth of the world's population cannot access even a gallon of safe drinking water a day.

Groundwater is one of the major systems being stressed. Overpumping, or extracting water faster than the underground systems recharge, has led to plummeting water tables, not only in the Middle East and northern Africa, but also in China, India, Iran, Mexico, and the U.S. The Ogallala aquifer, one of the world's largest, stretches under parts of eight states in the High Plains of the central U.S., from South Dakota to Texas. Water began collecting in porous sediments there some 5 million years ago; a geologically slow rate of recharge means that deep wells still bring up water from the end of the last Ice Age, more than 10,000 years ago, making it truly "fossil water." But the aquifer is being pumped out many times faster than it can be replenished. Between the early 1900s, when the Ogallala was first tapped for irrigation, and 2005, the water table dropped by more than 150 feet in some parts of Texas, Oklahoma, and Kansas. The raising of crops has become uneconomical for some Great Plains farmers, and further depletions could have substantial ripple effects on billions of people around the world who depend on American farm products.

As more land is paved over, rainwater can no longer soak into the ground or evaporate slowly to recharge the system. In coastal areas, a falling water table may open an aquifer to an influx of saltwater, impairing or even ruining it as a freshwater source.

Human activities are affecting other aquatic systems as well. Canals, dams, and levees that impede the natural flow of water can change not only the absolute quantity but the quality of water downstream: its concentration of pollutants, its sediment load, its temperature, and so on. People on both sides of the barrier

are affected, whether they are growing crops or fishing for sport. Those changes can also severely alter or destroy the habitats of other species. More than half the wetlands in parts of Australia, Europe, New Zealand, and North America were destroyed during the twentieth century. When people divert water into desert regions to maintain thirsty crops, luxurious green lawns, and golf courses—instead of growing drought-adapted crops and native and ornamental plants—water resources are decimated. Even high-volume rivers such as the Colorado, the Ganges, and the Nile have been reduced, in some places, to polluted trickles.

In water-rich regions, people may wonder how their actions could have any effect on how people use water in water-deprived areas. But consumer choices obviously help drive what agriculture and industry produce and how they produce it. If agriculture and industry account for more than 90 percent of water usage, our closets, cupboards, desks, and refrigerators are filled with what has been termed "virtual water": products that require water for their growth, manufacture, and packaging. Those products now come from all over the world, including from places with limited water resources.

More than 700 gallons of water are needed to grow enough cotton to make a T-shirt. Your choice to buy the shirt could lead farmers in arid Central Asia to divert water to irrigate a cotton crop. Although poor farmers may welcome the cash, such diversions have led, for instance, to a 75 percent loss of volume in the Aral Sea. Once the fourth-largest inland body of water by area, the Aral has now shrunk so much that its former lakebed is littered with rusty ships, rimmed with abandoned fishing villages miles from the water's edge, and scoured by storms of toxic dust.

Conserving water helps not only to preserve irreplaceable natural resources such as the Aral, but also to reduce the strain on urban wastewater management systems. Wastewater is costly to treat, and requires continuous investment to ensure that the water we return to our waterways is as clean as possible. During storms, rainwater runs off the pavement, collecting pollutants as it goes. Where storm sewers and sanitary sewers are connected, the influx of storm water can overwhelm sewage treatment facilities, leading to the release of untreated sewage and polluted storm water directly into local waterways. Forty billion gallons of such a toxic cocktail flow into the Hudson River and its estuary each year. Several towns and cities around the world are installing innovative solutions to such problems that also benefit surrounding ecosystems. Rainwater overflow, for instance, can be channeled into wetland systems instead of into storm sewers.

Human activities affect water quality in other ways as well. Particularly in large cities, once water has disappeared down the drain or into a storm sewer, it is rarely thought of again. But what becomes of the household chemicals poured daily into the water supply—cleansers, antibacterial soaps, medicines? Ecologists are just now learning about their downstream effects. One that is well documented is the disruption of growth and reproduction in frogs and fish. Cities with sophisticated treatment systems can filter out many chemicals, but antibiotics, hormones, and antibacterial compounds remain hard to handle.

The UN estimates that by 2025, forty-eight nations, with a combined population of 2.8 billion, will face freshwater "stress" or "scarcity." Water shortages already impede development, perpetuate poverty, and damage health in low- and middle-income countries. As populations grow and the demand for water increases, problems will intensify and will not be contained within national borders. Population displacements and conflict over shared surface and groundwater resources are bound to exacerbate international turmoil. It is no coincidence that the word "rival" derives from the Latin word for "one living on an opposite bank of a stream from another."

The world also faces the uncertain effects of global warming. The loss of mountain ice caps and glaciers, for instance, may alter the quantity and reliability of water for drinking, agriculture, and power generation. California's Central Valley, which produces a quarter of the food sold in the U.S., depends on timely seasonal snowmelt from surrounding mountains; farmers could face failing or lower-yielding crops as the climate warms and less water is available in the growing season.

Water policy makers have focused on technological solutions to increase water supplies—diverting surface water, pumping up groundwater, extracting the salt from seawater. Such solutions often have high costs, both monetary and environmental. And so the focus has shifted to reducing demand. Hydrologists estimate that as much as 60 percent of the water extracted from aquatic systems for human use is simply wasted—lost to leakage, evaporation, inefficient appliances, and human carelessness. Changes in various technologies and in everyday behavior could slash that number in half. Saving water in the home calls for installing water-efficient appliances and fixtures, fixing leaks, refilling water bottles from the tap, landscaping with native plants, and generally being more conscious about water use. Municipalities could construct wetlands or, better yet, refrain from destroying existing ones. Towns and businesses could pave with a permeable material that enables water to seep back into aquifers. Industries and municipalities can reuse water that has been treated but does not reach drinking-water standards. A bounty of choices is available, once we decide to stop taking water for granted. □

To find Web link

A SPECIAL BREW

Investigators still can't completely explain the strange molecular workings of water.

By Christopher J. Mundy, Shawn M. Kathmann, and Gregory K. Schenter

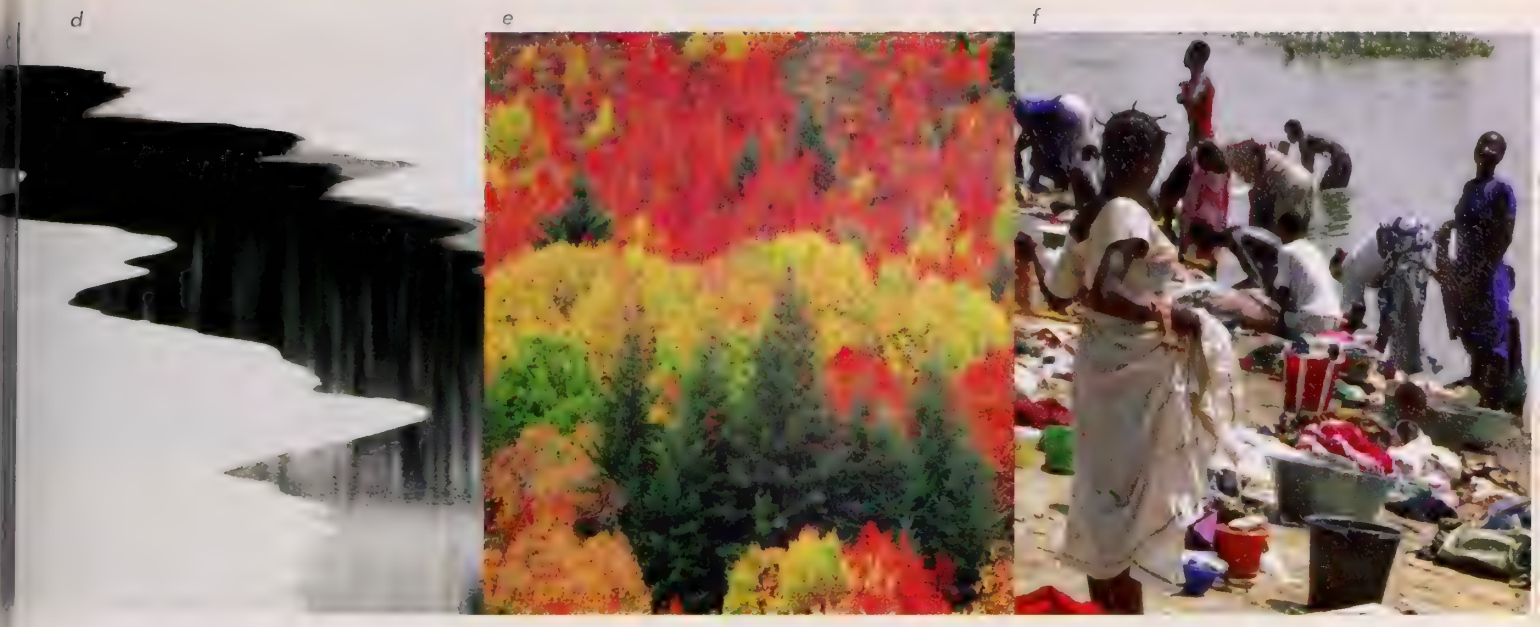
As children, we have all lain in the grass and looked up at the clouds. Sometimes they seemed to take on the shape of an animal, a favorite plaything, a familiar face. For many of us, such daydreaming segued into a deeper curiosity. What are the clouds? we wondered. What are they made of?

From an adult perspective, the answer seems obvious: water. Stand among the clouds on a mountaintop, and you can feel their moisture. Watch the plump white clouds of a sunny day transform into dark, daunting behemoths, and before long, sheets of water come pouring down. The common wisdom that clouds presage the weather is grounded in a less well known fact: the unique properties of water—in particular, its capacity to transport enormous quantities of energy—are what give the weather its variability, its energy, and its occasional violence.

Of course, our relationship with water goes far beyond the weather. We have fun with it whenever we go skiing or skating, boating, fishing, or swimming. The pleasure of a cold glass of thirst-quenching water on a hot summer day has a more serious basis, though. Without water, a human being can live only a few days. Every organism is made up mostly of water, and the substance covers nearly three-quarters of the Earth's surface.

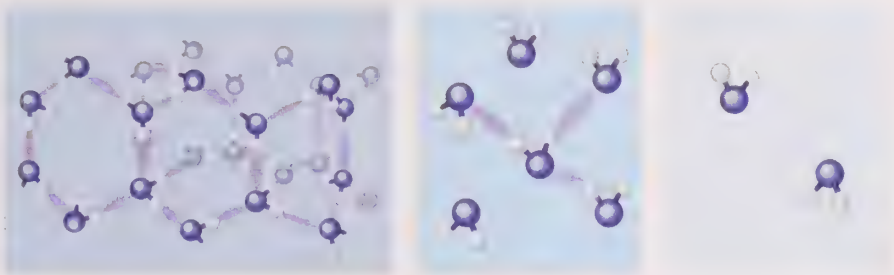
Yet this commonplace, familiar, and essential stuff of life is also quite peculiar, as substances go. For example, if the water molecule (H_2O) acted in bulk like other small molecules—oxygen (O_2), carbon monoxide (CO), nitrogen (N_2)—it would be a gas under the conditions prevailing on Earth. Instead, water occurs in all three states of matter: solid, liquid, and gas. Furthermore, water reaches its maximum density in its liquid form, at 39.2 degrees Fahrenheit (four degrees Celsius), just a few degrees above the freezing point. Thus water stays at the surface as it starts to freeze, and ice floats—a rare property shared by very few other substances. If its nature were otherwise, all temperate-zone lakes, ponds, rivers, and even oceans would eventually freeze solid from the bottom up, and life as we know it could not exist. Instead, a floating skin of ice cocoons the life in the liquid water beneath a layer of insulation, enabling it to persist under the frozen surface.

Another unusual and related property of ice is that, for a given temperature, increasing the pressure decreases



Strange properties of water: *(a) Cohesiveness enables water to travel upward from roots to leaves, against gravity. (b) High surface tension makes liquid water behave as if coated with an invisible film, which explains why insects can walk on it. (c) Water exists in all three phases—gas, liquid, and solid—at temperatures and pressures that are common on Earth. This familiar property is actually quite unusual. (d) Ice floats on liquid water; unlike most substances, water is most dense in its liquid phase. Lakes and even oceans would otherwise freeze solid in winter. (e) Water's abundance and heat capacity are, in part, responsible for the moderation of global temperature fluctuations and the gradual change of the seasons. (f) Water can dissolve a variety of substances, including acids, bases, and salts, earning it the moniker "universal solvent."*

the melting point. (Ordinary solids remain solid under pressure.) Even though these and other unusual bulk properties of water have been described in detail, a complete picture of how and why water acts the way it does is still lacking. It is not possible, for instance, to completely predict the properties of materials that incorporate water in their structure, either physically or chemically, or to design and tune their responses to various conditions. Perhaps the key to achieving that level of understanding and control is to study water on a molecular scale: how water molecules arrange themselves, how they interact, and how they dance with other kinds of molecules. We and our colleagues in the growing field of molecular science hope that by understanding exactly what happens at very small scales (around 10^{-10} meter, or a billionth of a meter), we can zoom out by a factor of a billion or so to understand and predict phenomena on a human scale.

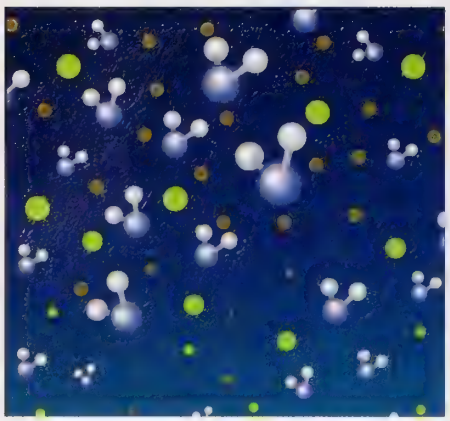


Ice (left) consists of a collection of hydrogen-bonded water molecules arranged in a pattern of hexagonal rings: oxygen atoms make up the vertices, and hydrogen bonds the edges. In liquid water (center), the water molecules are linked to their neighbors by three to four hydrogen bonds, which continually break and re-form. Water vapor (right), an important constituent of the atmosphere, consists of weakly interacting water molecules.

But we don't stop there. Because water is fundamental to all life on Earth, we also want to zoom out by another factor of 10 million to study its properties on a global scale.

Anyone who has visited the San Francisco Bay area has experienced local climate moderation. The city of San Francisco maintains a mild climate year-round, but just a few miles inland, where hills guard the bay, temperatures can soar to 90 degrees F (32.2 degrees C) in the summer and plummet to near freezing in the winter. The reason for this contrast, as most residents are well aware, is that the ocean moderates large temperature fluctuations. The same effect, on a global scale, is a factor in keeping seasonal temperature changes gradual rather than abrupt.

What governs the ocean's moderating effect is the large quantity and heat capacity of water. Heat capacity is the amount of heat energy that must be absorbed or released to raise or lower the temperature by a given amount. For example, it takes four times as much energy to warm a given mass



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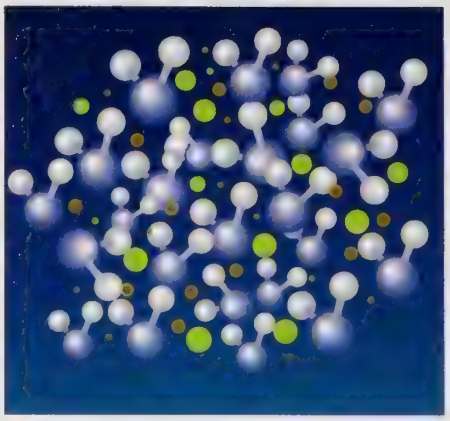

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of water by one degree Celsius as it does to warm the same mass of dry air by that amount. The heat capacity of water acts as a buffer, or perhaps a heavy flywheel, on climate, smoothing out what would otherwise be sharp changes in temperature.

Heat capacity is a good example of a macroscopic property of water that can be explained by what takes place at a molecular level. The chemical formula H_2O, instantly recognized round the world, indicates that the water molecule is a bound system of three atoms, two of hydrogen and one of oxygen. When you add heat (a form of energy) to a macroscopic sample of water molecules, the molecules increase their average speed and collide more often. The temperature of the sample is simply a measure of their average speed. Any energy added to or subtracted from the energy stored as such "translational" motion—movement from one place to another—changes the temperature.

But molecules can absorb and store energy in other ways, too. A water molecule can spin or rotate like a top, or it can wiggle and vibrate. Both rotational and vibrational motion can store energy. Yet they can't completely explain liquid water's observed heat capacity. In general, the more ways molecules can absorb heat energy without increasing the average speed of their translational motion—that is, the greater the molecules' capacity to act as heat sinks without raising the temperature of a substance—the greater the heat capacity of that substance.

You might think that no matter how little energy a molecule may have stored, the energy would still spread more or less evenly among all the possible kinds of motions. In other words, the energy would be partitioned among all possible "degrees of freedom." Because virtually all molecules made up of three atoms have the same number of degrees of freedom, their heat capacity, too, should not differ substantially. And sure enough, the heat capacity of the water molecule is about the same as that of other triatomic molecules.

Although the conclusion to the preceding argument agrees with the observed result, the argument itself is faulty. In the world of atoms and molecules, energy cannot be absorbed by the various kinds of molecular motions in arbitrarily small amounts. Rather, atoms and molecules are subject to the laws of quantum mechanics. In the quantum world, all changes in the energy stored by an atom or molecule are *quantized*. Each kind of molecular motion—translational, rotational, and vibrational—can absorb energy only in discrete chunks, whose sizes depend on the details of a particular molecule and the kind of motion involved. Expose a water molecule to the right-size chunk of incident energy (from the Sun, for instance), and the molecule will suddenly rotate or vibrate faster. Expose it to the wrong-size chunk, and nothing will happen; the molecule will simply "disregard" the passing energy. As it happens, the amount of energy available at the normal range of temperatures on Earth is only enough to generate translations and rotations of a single water molecule, but not enough to generate vibrations. Thus, on its own, the single water molecule isn't enough to explain the heat capacity of liquid water. In fact, the heat capacity of water *vapor* is smaller than that of liquid water by more than a factor of two! So the puzzle reemerges: how can the heat capacity of water be explained from a molecular point of view?

The solution is to look beyond the properties of a single water molecule and consider the interactions among the vast number of molecules in a bulk sample. Begin by considering the interaction of two water molecules. Each molecule is shaped like a tetrahedron, with the oxygen atom at its center. Each of the two hydrogen atoms lies at one of the four corners of the tetrahedron, and each one acts as a center of positive electric charge. When it bonds with hydrogen, the oxygen atom acquires two complementary

A cloud begins forming (a) as water molecules gather around dust (orange) and sulfuric acid (green) impurities in the air. Attracted by intermolecular forces, more molecules join the cluster (b). Eventually the cluster reaches a critical size—about 50 molecules—of less than 1 nanometer (c). Until this stage, the collection of molecules is highly unstable and may break up. Getting over the energy barrier of the critical cluster constitutes a phase transformation from gas to liquid. The growth process takes off (d) eventually resulting in condensation nuclei, made up of particles that differ in size by a factor of ten or even a thousand. A cloud droplet (e) ultimately emerges, made of 10^{15} molecules; it may eventually grow into a raindrop (f) of 10^{20} molecules.

centers of negative electronic charge, which cluster at the opposite two corners of the tetrahedron.

When the two water molecules are brought together, opposite charges attract. One of the sites of positive charge—a hydrogen atom—in one molecule becomes attracted to one of the negatively charged sites associated with the oxygen atom in the second molecule. This attractive interaction is known as a hydrogen bond. In liquid water, each molecule often forms four hydrogen bonds. Two of them link the two hydrogen atoms with the oxygen atoms of two other water molecules [*see illustration on page 33*]. The other two hydrogen bonds link the oxygen atom with hydrogen atoms of two more water molecules. Those bonds give rise to a stable network of tetrahedral water molecules. In the liquid the network extends only locally, and the hydrogen bonds continually break and re-form. But in ice, the network of tetrahedrons extends over a long range and becomes a relatively unchanging lattice.

Within a network of tetrahedrons, the number of ways incident energy can create rotations, twists, vibrations, and suchlike significantly rises. Each new mode of motion provides an additional degree of freedom, and so the heat capacity of the network far exceeds the heat capacity of a single constituent molecule. Note, though, that many other molecules, including other triatomic molecules such as carbon disulfide (CS_2), also form linked networks whose heat capacity far exceeds the heat capacity of one of their constituent molecules.

In fact, although it is not widely appreciated, the heat capacity of water, even within a linked network having many degrees of freedom, is not unusually large—provided the heat capacities are stated in units of energy per molecule or per mole, which is 6.02×10^{23} molecules of the substance. On that basis, the heat capacity of water is about the same as that of other triatomic molecules. In the appropriate units, for instance, the heat capacity of water is 75.3, whereas the heat capacity of carbon disulfide is 75.7.

Only when heat capacity is measured in the amount of energy per unit mass does the heat capacity of water look anomalously large. The reason is that the molecular mass of water is small compared with that of other triatomic molecules. Expressed in those units, the heat capacity of H_2O is more than four times that of CS_2.

The study of the various configurations of the hydrogen bond has made it possible for molecular scientists to explain a number of other anomalies of water. For example, in ice, the hydrogen bonds tend to be slightly longer than they are in the liquid phase, resulting in a larger volume and

thus the lower density of ice than of liquid H_2O. If ice is compressed, the hydrogen bonds shorten and become more like those in the liquid.

Stable hydrogen bonds also lead to the strong cohesive forces underlying the unusually high surface tension of water. Insects such as water striders take advantage of the surface tension when they skip across a pond—as if its surface were made of clear, flexible plastic. And the high cohesiveness and surface tension of water explain how long columns of watery suspensions can be drawn through extensive networks of blood vessels and even into tree canopies several hundred feet above the forest floor.

In its vapor form, **water** is the most important **greenhouse gas**, so it plays a **major role** in the **climate** of our planet.

Water is the third most abundant chemical compound in the Earth's atmosphere, after nitrogen and oxygen. It is present there both as a vapor, or gas, in which the water molecules dart about randomly and independent of one another, and as an aerosol, a mist of tiny liquid droplets or solid ice crystals that are suspended in air because they're too fine to fall to earth as rain or snow. In its vapor form, water is the most important greenhouse gas, so it plays a major role in the climate of our planet.

But when water takes the form of an aerosol, it is crucial to cloud formation and to the reflection and absorption of radiation. Water aerosols act as condensation nuclei for clouds—after all, clouds themselves are made up of relatively large aqueous aerosols. And water aerosols transform radiation in ways that, in turn, feed the factors that shape cloud development. Reaching a better understanding of how water aerosols affect climate has become increasingly important in the past several decades.

Water aerosols enter the atmosphere when waves break in the ocean or when vapor turns to liquid. The latter process, condensation, is in essence a battle between entropy and energy, order and disorder. As water molecules condense into their liquid state, they gain order but lose kinetic energy. The kinetic energy given up by the phase change is dumped as heat into the surrounding air, giving rise to a pocket of thermal instability that will drive yet another change in the weather as it equilibrates.

The physical process of condensation is "seeded," or nucleated, around tiny molecular impurities or perhaps a dust particle in the air. Once an "embryo" of the new liquid phase forms, more molecules tend to gather around it and glom onto it, attracted by intermolecular forces [*see illustration on pages 34–35*]. The larger the surface area of the growing cluster, or the stronger the intermolecular interaction, the larger the target area onto which more molecules and other nearby droplets can be pulled.

As the water cluster grows, it remains highly unstable until it reaches a certain critical size—the critical cluster —which is about fifty molecules. Precritical clusters can break up at any time into single water molecules. As it approaches the critical size, though, the cluster is also climbing to the "top" of an energy "hill." If it reaches the top and attains the critical size, it can then "roll down" the far side of the energy hill and undergo spontaneous, runaway growth. From fifty molecules, the cluster grows and agglomerates to the size of a condensation nucleus (10^8 molecules), then to a cloud droplet (10^{15} molecules), and finally to a raindrop (10^{20} molecules).

In 1998, members of our research team were among the first to measure the chemical identity of the nucleated particles and to show that the chemical interactions among them have a profound influence on the aerosol formation rate. We modeled the rate of evaporation of molecules from clusters, developed a molecular simulation strategy to compute the relevant kinetics, and applied the strategy to water. We found that the molecular interactions between water and the initial nucleating particles—whether dust, sea salt, sulfuric acid, ions, or some other substance—may significantly affect the rate of aerosol formation. That rate affects the distribution, duration, and precipitation processes in clouds, and thus their tendency to reflect, transmit, or absorb the Sun's radiant heat. All those properties in turn influence the reflectivity of the Earth and thus the global climate.

Atmospheric scientists have yet to determine the exact nature of that influence. One possibility is that if cluster droplets grow more quickly, more clouds may form, helping moderate global warming by providing more cloud cover. On the other hand, faster droplet growth could accelerate the production of rain, causing clouds to dissipate sooner. That would lead to a less cloudy world, and faster warming.

As we molecular scientists learn more about water, we are continually reminded that we have merely "scratched the surface" of its secrets. The mechanisms of its impact on life are still something of a mystery. Coaxing Mother Nature to reveal further secrets about water will require the full interdisciplinary sophistication of today's scientific toolbox. But since water is the wellspring of life, we owe it to ourselves—and everyone else—to explore all we can about its strange and intriguing properties. □

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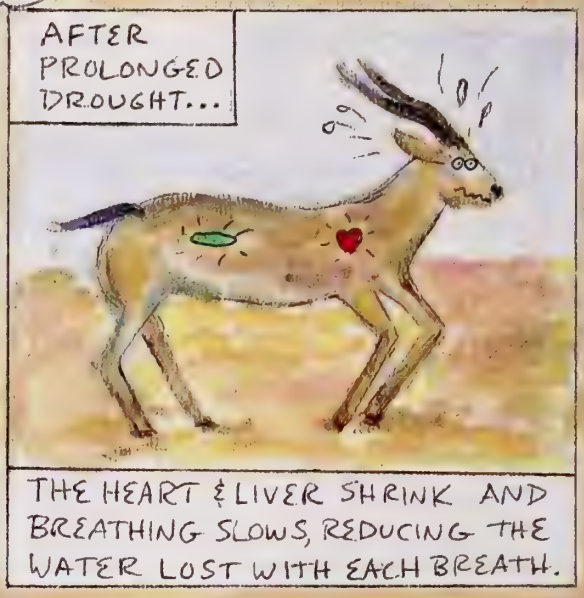
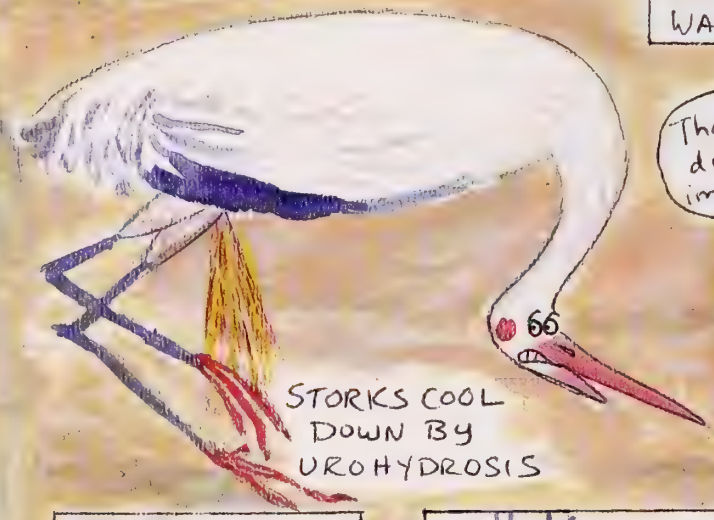
WATER IN THE WILD

by Dolly Setton

SAUDI ARABIAN GAZELLE



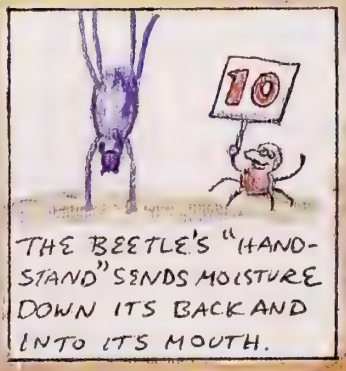
THE HEART & LIVER SHRINK AND BREATHING SLOWS, REDUCING THE WATER LOST WITH EACH BREATH.



STORKS COOL DOWN BY UROHYDROSIS

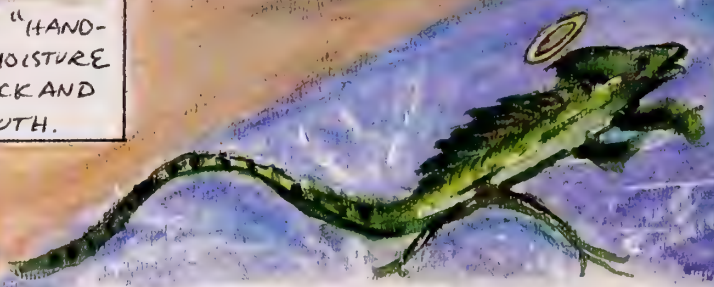
FRESHWATER FISHES KEEP A HEALTHY BALANCE OF SALT AND WATER BY RELEASING A STEADY STREAM OF URINE—IT'S CALLED OSMOREGULATION.

NAMIB BEETLE SCURRIES UP A DUNE TO CATCH WATER IN A FOG.



THE BEETLE'S "HAND-STAND" SENDS MOISTURE DOWN ITS BACK AND INTO ITS MOUTH.

NAMIB LIZARDS DANCE ON HOT DUNES AND GET ALL THEIR WATER FROM FOG



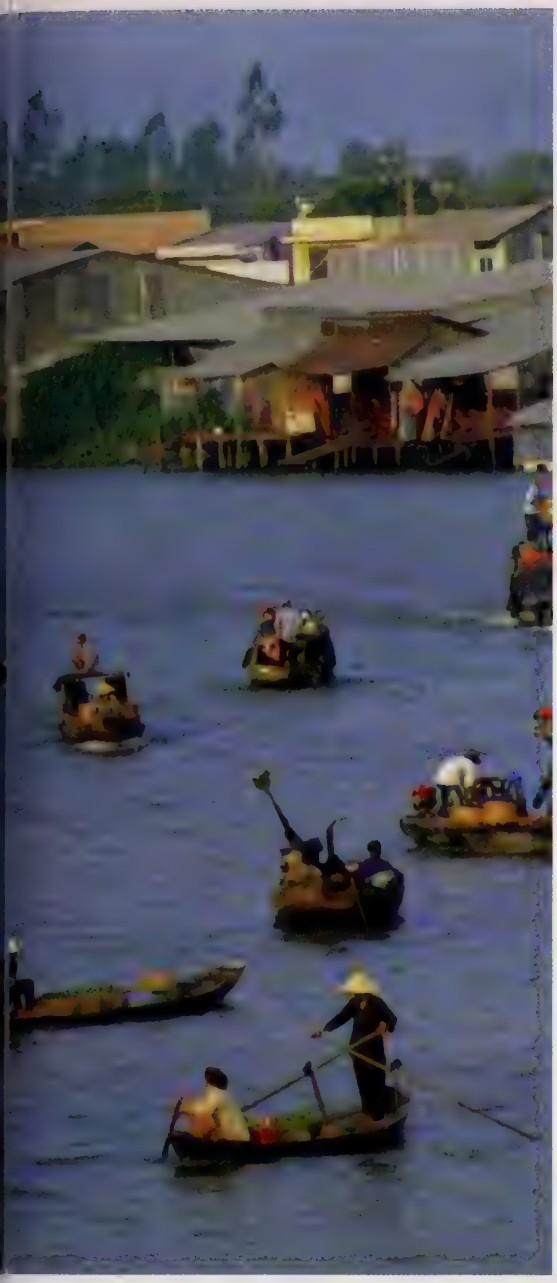
JESUS CHRIST LIZARDS—YES, THEIR REAL NAME!—RUN ON WATER.

BATS RETREAT TO CAVES DURING THE DAY TO STAY COOL AND CONSERVE WATER.
H_2O
GIGGA-GIGGA!
OWLS AND QUAILS FLUTTER THEIR THROATS TO EVAPORATE WATER AND COOL THEMSELVES DOWN.
Finally, a bat signal for bats, not men in tights!
THE KANGAROO RAT CREATES WATER FROM DRY SEEDS.
Does my tail look fat?
Yes, but that's a good thing!
GILA MONSTERS STORE WATER IN THEIR TAILS.
PREDATORY GANNETS HIT THE WATER AT 70 MPH, PROTECTED BY AIR SACS IN THE FACE AND CHEST.
BRRRR
EXTREMOPHILES!
OUCH! OUCH!
GIANT TUBE WORMS LIVE WITH THEIR HEADS IN FREEZING WATER AND THEIR BUTTS IN BOILING WATER.
1
How dry I am.
2
Hallelujah!
TARDIGRADES SUSPEND THEIR VITAL FUNCTIONS FOR AS LONG AS 100 YEARS IF THERE'S NO WATER AROUND.

SOLD DOWN THE RIVER

Dried up, dammed, polluted, overfished—freshwater habitats around the world are becoming less and less hospitable to wildlife.

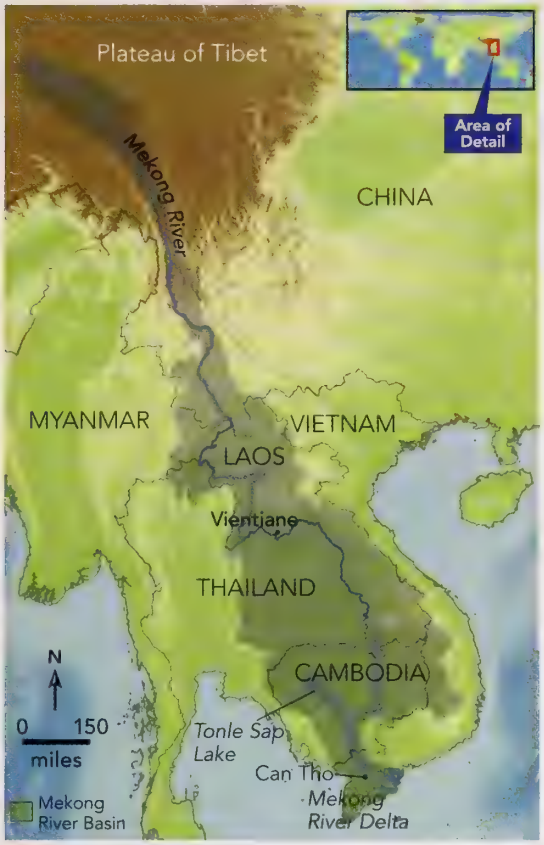
By Eleanor J. Sterling and Merry D. Camhi



Boat traffic at a floating market near the city of Can Tho, Vietnam, jams a branch of the Mekong River. Some 65 million people live in the 300,000-square-mile Mekong River Basin, also home to a diverse freshwater fauna.

The banks of the Mekong River in Vientiane, the capital of Laos, can be a lovely retreat at sunset. The river sweeps alongside the city in a wide elbow curve, offering a panoramic view of tranquil waters and tree-lined shores. Thailand rests on the opposite bank, seeming farther away than its half-mile distance. And as the setting sun lights the water ablaze, birds skim the surface, and fish make themselves known with the occasional splash, making an evening walk along the riverbank a pure delight.

At the start of a recent visit to Vientiane, however, one of us (Sterling) wound her way through the city to the river, anticipating a cool breeze and a quiet walk after a sweltering workday, only to stare into a scene from the desert. Clouds of dust rose from the riverbed, where a group of kids were playing soccer. Beyond that bone-dry sandbar, a vestige of the river was just visible as a thin stream along the far bank. By all appearances, one could easily have walked across to Thailand.



Such radical fluctuations are natural to the Mekong, and whole communities—human and wild—are adapted to its periodic floods and droughts. The river swells when rainfall rushes down its tributaries and shrinks again in drier weather. But the rise and fall of the Mekong is increasingly dictated by energy use in China and Thailand. Upriver hydroelectric dams dampen the fluctuations and change the timing of floods and dry spells, affecting water-dependent wildlife hundreds of miles away. The extent of those changes is likely to grow as more dams, scheduled for construction, make their mark on the river.

The dams are just one of the many troubles that confront the river and its denizens; water extractions, pollution, invasive species, and overfishing also threaten the ecosystem's health. And the Mekong's woes mirror those of freshwater systems worldwide, which are increasingly pressured by a growing human population that makes ever-greater water demands. The scale is enormous: people now appropriate more than half of the world's accessible surface freshwater, leaving precious little for natural systems and other species to thrive.

As a result, even as the human population of the globe has doubled, many species that depend on freshwater ecosystems have suffered steep declines. The list would bring tears to a conservationist's eyes: in the past three decades, a fifth of the world's water birds, a third of freshwater mammals,

a third of amphibians, and more than half of freshwater turtles and crocodiles have become either threatened, endangered, or extinct. Freshwater fishes represent a quarter of the world's living vertebrate species, and yet more than a third are threatened or endangered. The ecology of freshwater systems may be irreversibly damaged if we humans don't improve the way we treat them.

The Mekong's name translates from Lao as "mother of the waters." It's no wonder: the river snakes some 3,000 miles from its headwaters on the Tibetan Plateau to its outlet through the Mekong River Delta into the South China Sea. It and the uncountable "feeder" rivers and streams in Cambodia, China, Laos, Myanmar, Thailand, and Vietnam make up the 300,000-square-mile Mekong River Basin [*see map on preceding page*].

That mesh of waterways is one of the most productive and diverse ecosystems on Earth, supporting more than 6,000 species of vertebrates alone. Its fish fauna, with some 2,000 species, of which sixty-two are endemic, exceeds all but those of the Amazon and Congo river basins. The wetlands harbor several threatened and endangered birds and mammals, including the eastern sarus crane, *Grus antigone sharpii*; the Bengal florican, *Houbaropsis bengalensis*; and the hairy-nosed otter, *Lutra sumatrana*, which was recently rediscovered after having been feared extinct. Sixty-five million people live there, too, 80 percent of them dependent on the river for their livelihood as farmers and fishers.

The Mekong River Basin is a microcosm of the Earth's freshwater resources—it includes almost all of the natural forms freshwater takes on Earth: groundwater, lakes, ponds, streams, and wetlands. (Wetlands are defined as shallow, often intermittently wet habitats, such as bogs, floodplains, marshes, and swamps.) Together, freshwater ecosystems cover less than 1 percent of the Earth's surface and hold a mere 0.008 percent of its water, but they support about 100,000 animal species—an inordinately large number for their size relative to marine and terrestrial habitats. That freshwater fauna includes a third of all known vertebrates and a whopping 40 percent of all known fish species.

Their rich biodiversity aside, freshwater systems bestow untold—and underappreciated—benefits on people. Indeed, they are the very foundation of our lives and economies. The value of all the services freshwater ecosystems provide worldwide, such as drinking water, irrigation for agriculture, and climate regulation, has been estimated at $70 billion per year—a figure that assumes, rather delusionally, that one could purchase the services elsewhere if they became unavailable in nature.

Dams are a dramatic example of a human activity that degrades freshwater ecosystems. Built to control flooding, store water, and generate electricity, dams have numerous ecologically disastrous side effects. They impede the movement and migration of aquatic species; some kill animals in turbines; and they change the timing and amount of flow downriver, which interferes with the reproductive cycles of fishes, frogs, and water birds that depend on seasonal flooding.

About a dozen hydroelectric dams in the Mekong River Basin provide the bulk of the region's energy—and another hundred or so are in the planning stages. To date, China has built two dams across the upper mainstream, but there are none across the lower mainstream—in fact, the Mekong is one of the world's few major rivers with so few mainstream dams. That may soon change: local governments view the free-flowing Mekong as an underutilized economic resource. Worldwide, an average of two large dams have gone up each day for the past fifty years, and today there are more than 45,000 dams taller than forty-five feet. Fortunately, increased awareness of the environmental problems they cause has contributed to a slowdown of

Water-snake hunter, opposite page at left, brings his catch to market on Tonle Sap Lake in Cambodia. The capture of water snakes—mainly to feed crocodiles raised for their hides—has reached unsustainable levels. Workers tend a rice paddy in Laos, top center of these two pages; agricultural runoff degrades the Mekong's water quality. About a dozen dams now partition the river and its tributaries and several more are under construction, including the Nam Theun 2 dam in Laos, above right. Dams provide irrigation water and electricity for the region's growing population, but can harm wildlife.

large-dam construction in the United States and Europe. In the Mekong River Basin and elsewhere, however, big dams continue to rise.

Species along the Mekong, as in other freshwater systems, depend on natural flood cycles for nutrients and for transportation to and from spawning grounds. More than 90 percent of the fish species in the Mekong watershed spawn not in rivers, but in seasonal lakes or periodically flooded forests and fields. Flow patterns altered by dams and other projects could prevent those species from reproducing. In addition to building dams, countries along the Mekong are destroying or modifying rapids and other natural features to improve navigation—changes that will disturb critical fish habitats and alter downstream water flow.

Another destructive practice is crop irrigation, the biggest consumer of freshwater both along the Mekong and worldwide. Most of the water withdrawn from the Mekong goes to irrigating crops, mainly rice. Demand for irrigation water has risen dramatically in the past decade, as new acreage has come under cultivation and new irrigation schemes have enabled farmers to produce a second or third rice crop each year. Removing so much water from freshwater systems can be devastating for wildlife, exacerbating flow problems caused by upstream dams.

Worldwide, irrigation guzzles about 70 percent of the freshwater people use. To grow food for expanding human populations, people divert rivers, drain inland seas, and extract fossil groundwater collected over thousands of years, often at unsustainable rates. Worse, current agricultural practices often waste as much water as they use: about half the water that flows through conventional irrigation systems never actually reaches a crop plant. A lesser—though still formidable—amount of water is siphoned off to slake the thirst of cities and industry, and when you add it all together, it's clear that people are using more than their fair share. The Mekong still manages to reach the sea. But at least ten other major rivers, including the Colorado, Ganges, Jordan, Nile, Rio Grande, and Yellow, now regularly run dry before they reach their outlets.

Agriculture, in addition to being the greatest consumer of freshwater, is also a major polluter—another bane for wildlife. In the Mekong River Basin, agriculture relies heavily on pesticides and fertilizers; it also drives deforestation, which causes erosion. Chemical, nutrient, and sediment runoff from farms winds up in the Mekong River Delta, where it degrades water quality, shifts natural nutrient cycles, and alters wildlife habitat. The six nations in the Mekong watershed have initiated a regional program to encourage agricultural development. If not done mindfully, the accelerated development could worsen water quality.

Other countries are already contending with the effects of major pollution. Fertilizer, pesticide, and livestock-waste runoff from farms in the American Midwest, for example, have created a dead zone at the mouth of the Mississippi River in the Gulf of Mexico. There, coastal algae populations thrive on the influx of nutrients and the misfortune of their natural predators, which are often curtailed by the pesticides. From spring until late summer, immense algal blooms rob the Gulf's water of oxygen. Such hypoxic conditions chase

the swimming creatures away and kill clams and other sedentary species on the spot. The Gulf's seasonal dead zone now encompasses more than 8,000 square miles, an area the size of New Jersey, every spring and summer. Much smaller dead zones occur on the Mekong, too. Worldwide, there are 146, every one increasing in size, intensity, and often duration.

Besides agricultural runoff, pollution from industry and municipalities is also a big problem for freshwater systems. In addition to contributing extra nutrients that promote algal overgrowth, municipal wastewater also carries thousands of chemicals from products used in daily life: cosmetics, soaps, pharmaceuticals, cleaning supplies, and more. Most of it winds up in aquatic systems.

The long-term consequences of dumping so many chemicals in the water are just coming to light. More than 200 species are thought to have adverse reactions to endocrine disruptors—such as estrogen and its chemical mimics—that get into the environment via human and veterinary pharmaceuticals in wastewater and farm runoff. Sightings of frogs with deformities, such as extra legs, mushroomed in the Midwest about a decade ago. Ecologists think chemicals or an interaction between chemicals and parasites could be causing the deformities. Indeed, chemicals in freshwater may be a factor in the alarmingly sharp worldwide decline of amphibians.

Laotian fishmonger offers Mekong giant catfish for sale. The giant catfish, which can grow to nine feet long and 600 pounds, is now critically endangered.

Biological introductions to waterways, like chemical introductions, are extremely problematic. In their own communities, most species are held in check by natural predators or other environmental constraints. But organisms from afar can crowd, devour, or outcompete native species in their new neighborhoods, and can even change entire ecosystems. Most biological introductions by people are accidental, but some, such as fishes stocked for anglers or plants brought in to stabilize soils, are intentional.

Mimosa pigra, a spiny shrub native to the Americas and planted abroad as an ornamental or to control erosion, is now one of the world's worst aquatic invasive species. Once established, it quickly forms dense stands and outcompetes native plants. First spotted on the Mekong in 1979, it spreads in floodwaters and in truckloads of construction sand, and is now devastating parts of the watershed. The mimosa has taken over several irreplaceable wetlands, doubling its area almost every year in some places. Several endangered water birds that depend on native grasses for food and shelter are undergoing population declines as mimosa stands replace their habitat.

Controlling freshwater invaders and mitigating the damage they cause costs some 9 billion dollars each year in the U.S. alone. Yet the rate of invasions everywhere is on the rise as global commerce, trade, and travel increase.

So much for the organisms people add to freshwater systems. What about the ones—too many—that we take out? Overexploitation for food, medicine, and recreation poses a major threat to freshwater birds, crocodiles, fishes, frogs, and turtles, as well as some invertebrates. More than 40 million people rely on the waters of the Mekong River Basin for their protein and income, and they are overfishing numerous species—indeed entire fish assemblages in certain areas—as a result.

The Mekong giant catfish, *Pangasianodon gigas,* is just one of the region's struggling, overfished residents. Reaching nine feet in length and more than 600 pounds, it is the world's largest catfish [*see photograph above*]. With such grand proportions, a jackpot of succulent flesh that once sold at a premium to urban restaurants, the giant catfish was a fisherman's prize catch. In the mid-twentieth century, hundreds of giant catfish—a naturally rare species—were caught each year, but recently the annual catch has declined to fewer than ten. Overfishing is the main cause of the decline, but habitat fragmentation and alteration of spawning grounds by dams and navigation projects also contribute. Today, the giant catfish is critically endangered, its range is greatly restricted, and the average size of individuals is declining. In recent years, Cambodia, Laos, and Thailand have outlawed catching the giant catfish. But the species is migratory, so a regional agreement may be necessary to prevent its demise.

Fish aren't the only victims of overexploitation. As many as 10,000 water snakes are fished from Tonle Sap Lake each day. The water snakes mainly go to feed hungry crocodiles raised for commercial export; they substitute for fish, whose populations have declined. People are fishing down the food chain in the Mekong River Basin, as in

so many freshwater and marine systems. After depleting the top predators and the largest species, fishermen turn their nets on successively smaller organisms.

The upshot of all those assaults is that freshwater organisms rank among the world's most threatened species. Data on global trends are sparse, but what biologists do know paints a bleak picture of striking declines across taxa. Freshwater dragonflies, damselflies, mussels, fishes, amphibians, reptiles, birds, and mammals—all are suffering. To prevent a wave of irreversible extinctions and ecosystem collapses, people need to take better care of fragile freshwater habitats.

Fortunately, there is much people can do. We can remove obsolete dams and design new ones that take into account natural patterns of river flow. We can reduce the need for massive water extractions by changing the way we grow our food and our cities; more efficient irrigation techniques and increased capture of rainwater, even in wet areas, would help. Conservation may be the best "new" source of water, particularly as climate change begins to shift water supplies globally. We can start to reduce our polluting ways by avoiding harmful chemicals in the first place. In the end, keeping more water in freshwater habitats and maintaining its quality must be a top global priority.

The future of the Mekong lies in the balance. Today, it remains one of the world's least-degraded large rivers, but the primacy of economic growth threatens to tip the balance towards decline across the entire river system. Still, there are hopeful signs. Several transboundary initiatives are in the works among the six nations that share the Mekong, which should help balance the needs of people and wildlife. Then there's the Mekong River Commission. Formed in the 1950s, the commission has moved away from its original focus on dams and irrigation projects toward more holistic management that takes environmental health into consideration. But the MRC is only as strong as the resolve of the governments it represents; China and Myanmar are not members, which may undermine its effectiveness in protecting the basin.

Internationally, the Ramsar Convention on Wetlands, with 155 signatory nations, guides conservation of 1,675 globally important wetland ecosystems. As with the Mekong River Commission, however, Ramsar's strength rests on the decisions of its signatories: it has no enforcement mechanism. It should come as no surprise, then, that—as with conservation choices in general—most decision makers have consistently chosen short-term economic gain over the long-term health of aquatic systems.

Current societies value few things more than gold. But though one can survive, even live well, without gold, the same is not true for water. Ultimately, the true value of gold is reduced to this: it can buy you fresh, clean water—if there's any for sale. □

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Outhouse in Dhaka, the capital of Bangladesh, provides the only kind of "plumbing" for the surrounding slum. According to the World Bank, one-third of Dhaka's 12 million residents lack sanitation facilities, and almost one-third still lack safe drinking water.

DANGEROUS WATERS

Twenty percent of the people on Earth lack access to clean water. And even that dismal number is likely to grow.

by Sharon P. Nappier, Robert S. Lawrence, Kellogg J. Schwab

An estimated **1,000 new synthetic compounds** are introduced **every year**—some of them inevitably **seep into drinking-water** sources.

Drought in Australia. Water shortages in northern China. The desertification of western Africa. Almost daily, such headlines roll off the presses and issue from the airwaves.

Undoubtedly, diminished access to freshwater is a dire threat to people around the world. But consider the condition of the water when it finally trickles down people's throats. Infectious pathogens and harmful chemicals—from parasites to poisons—contaminate the world's freshwater and contribute to the deaths of millions of people worldwide every year. Understanding the effects of those contaminants holds the key to protecting our drinking water. And figuring out how we are exposed to harmful agents is the first order of business in choosing proper water-treatment techniques.

The burden of those agents weighs heavily on communities around the world. Nearly 2 million people—most of them children under five—die every year from diarrheal diseases. That statistic is not surprising when you realize just how much dirty water flows, or in many cases lies stagnant, across the continents. Nearly 20 percent of the 6.6 billion people in the world lack access to a supply of clean water, and 40 percent lack safe sanitation facilities. No new headlines there: as far back as 1981 the United Nations recognized the need for improved water supplies and sponsored a water-themed decade through 1990, in hopes of rallying international aid. Yet the percentage of people who have sufficient access to clean water supplies has remained fairly static.

Arguably, the battle is uphill. As quickly as innovative filters and water-transport systems enter the market, new contaminants and diseases arise, populations grow, and competing demands for water increase. Certain microorganisms can be elusive, causing severe illness at doses as low as one infectious organism per drink of water. And those disease-causing organisms don't stand still while we figure out how to combat them: dirty water can lead to increased virulence, as in the case of antibiotic-resistant bacteria. Battling, let alone eliminating, those ever-changing organisms, along with the plethora of synthetic contaminants, seems only to be getting more difficult.

One thing will never change: people need water for survival. Circulating inside, outside, and across our cells, water constitutes as much as 70 percent of our body weight. Although we may survive four weeks without food, our bodies last, at best, only a few days without water. Furthermore, we use water for the most basic daily activities: drinking, cooking, bathing, washing, and sanitation.

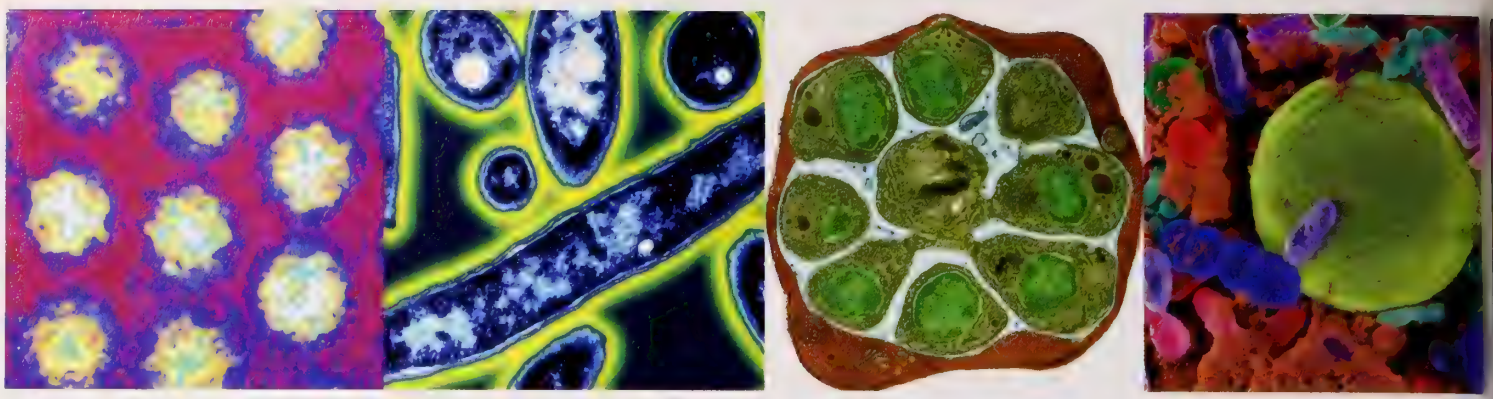
For at least the past six thousand years, civilizations have understood the need to engineer water treatment techniques. Greek and Sanskrit texts discuss approaches to water sanitation that include boiling, straining, exposing to sunlight, and charcoal filtering. The ancient Egyptians employed coagulants—chemicals that are frequently used even today to remove suspended particles in drinking water—and other methods of purification. The earliest large-scale water treatment plants, such as the one built in 1804 to serve the city of Paisley, Scotland, used slow-sand filtration. By the 1850s London was sending all of its city water through sand filters and saw a dramatic reduction in cholera cases.

The discovery of chlorine as a microbicide in the early 1900s was a turning point in drinking-water engineering. That, in turn, led to a major advance in public health. Chlorination was initiated in the United States around 1910, and during the next several decades change was evident: the previously high mortality rate from typhoid fever—twenty-five deaths per 100,000—plummeted to almost zero. Although chlorine readily inactivates viruses and bacteria, its killing power flags when faced with hardy protozoan oocysts (developing cells), such as those of *Cryptosporidium parvum*—an agent of diarrheal disease. Another, and perhaps even nastier, drawback is that chlorine and organic matter may create carcinogenic by-products when they mix in the treatment plant. Nevertheless, chlorine is still one of the cheapest and most effective disinfectants in use today.

No panacea for water disinfection exists, however. To ensure that the water supply is clean enough to drink, most modern drinking-water plants amass an arsenal of treatment options. A multibarrier approach might include physical processes such as coagulation and flocculation (creating clumps of particles), sedimentation, and filtration, in conjunction with disinfectants such as chlorine, chlorine dioxide, chloramines, or ozone.

Such systems for cleansing community water are public investments that pay dividends. Clean water improves general health and reduces health-care costs, thereby enabling greater productivity among community members and redirection of public funds to other pressing needs. Unfortunately, rural and low-income localities cannot afford the infrastructure required for large, centralized drinking-water facilities.

On a global scale, of course, an ideal filter is natural vegetation. Protecting entire watersheds could vastly im-



Water-associated pathogens that threaten human health include, from left to right, Norovirus, *the Norwalk virus;* Legionella, *the bacterium responsible for Legionnaires' disease, a kind of pneumonia;* Plasmodium, *the protozoan that causes malaria (pictured here inside a red blood cell);* Cryptosporidium, *a protozoan that causes severe diarrhea and resists treatment with chlorine;* Vibrio cholerae, *the cholera bacterium; and* Giardia lamblia, *another protozoan that causes diarrhea.*

prove water quality worldwide; benefits could come from actions as simple as maintaining hillside growth to prevent soil erosion and flooding. But because many watersheds span several states or even countries, most management plans are politically complex. A comprehensive watershed-management plan must incorporate multiple stakeholders' needs and conflicting interests.

Water scarcity goes hand in hand with disease. As renewable freshwater becomes a dearer commodity worldwide, waterborne disease agents and other contaminants become harder to control. When dealing with diarrheal diseases, for instance, the quantity of available water often matters more than the quality, both to fend off the disease and to foil its spread. Then there's trachoma, a condition that can cause blindness; today it affects 6 million people and is associated with poor personal hygiene, often resulting from a dearth of water.

Every person, every day, needs at least thirteen gallons of water for drinking, cooking, bathing, and sanitation. In 1990 more than a billion of the world's people used less than that. By contrast, average per-capita water usage in the U.S. now exceeds 150 gallons a day. That discrepancy illustrates how the level of personal use correlates not only with the economic development of a region, but also with the degree of urbanization and with the overall public health in the region.

All that water filling swimming pools and soaking gardens might seem extraordinarily wasteful, but only 8 percent of the planet's freshwater supply goes toward personal, household, and municipal water use. Agriculture accounts for 70 percent, and industry for 22 percent, of current freshwater use. It takes more than fifty gallons of water to produce a single cup of milk. That's modest as virtual water content goes: consider a quarter-pound hamburger (470 gallons) or a cotton T-shirt (520 gallons). Then consider how many cotton T-shirts are tucked away in your closets. It's no surprise that demand is exceeding supply.

Daily water needs are exceedingly hard to meet in areas where rapid urbanization is taking place. Antiquated water-supply systems are simply not equipped to provide enough water and sanitation to people living in progressively crowded shantytowns or on the urban fringe. About half the world's people are now city dwellers. This new urban majority puts great stress on infrastructure, increasing the likelihood that illegal connections will be inserted into existing water systems and that, as a result, the piped drinking water will become contaminated.

Countries undergoing urban population booms often face acute microbial hazards. In countries where per-capita income is low, roughly 200 children under the age of five die every hour from a water-associated microbial infection. Many of the infections derive from the ingestion of water contaminated with human or animal feces that carry pathogenic bacteria, viruses, protozoa, or helminthes. That's the classic, but not the only, pathway for waterborne disease spread.

Exposure to contaminated water extends beyond the drinking fountain. Many diseases, once introduced into a population, can spread via person-to-person contact, in aerosol droplets, or through food preparation, rather than direct consumption of contaminated water. For example, malaria-carrying mosquitoes use stagnant water as a breeding ground; *Giardia* can be acquired during a swim in a local lake; clothing or bedding may carry scabies mites; noroviruses can be transmitted by eating oysters [*see photomicrographs on these two pages*].

Emerging infectious diseases (the ones whose incidence in humans has increased in the past two decades or threat-

ens to increase soon) have recently caused some public-health scares. Noroviruses—headlined for causing cruise ship infections—are already on the rise. *Cryptosporidium parvum* sickened some 400,000 residents of Milwaukee, Wisconsin in 1993, when the local water-treatment process was changed in what had seemed to be a minor way. *E. coli* O157:H7 is another of the more common emerging infectious pathogens in the U.S. joining the hefty ranks of dangerous bacteria, many of which are becoming resistant to multiple standard antibiotics.

But pathogenic microorganisms are not the sole cause of water-associated illnesses. Chemicals, too, pose serious risks. About a thousand new synthetic compounds are introduced every year, joining the ranks of tens of thousands more that are already in widespread use—dioxins, PCBs, and halogenated hydrocarbons included. Many inevitably seep into the water system and accumulate in the food chain. In the United States, for instance, some 700 chemicals have been detected in drinking water sources, and more than a hundred of those chemicals are considered highly toxic.

Advanced technologies enable investigators to detect harmful chemicals in the water supply, even in low concentrations—a critical step, since their effects on human health are often unknown. Several emerging chemicals of utmost concern are fuel additives, such as methyl tertiary-butyl ether, or MTBE; by-products of disinfection; antibiotics, hormones, and psychoactive drugs; the antibacterial soap ingredients triclocarban and triclosan; and persistent organic pollutants, such as perfluorinated chemicals and phthalates.

Most people have a sufficiently robust immune system to handle exposure to a certain amount of water pollutants. But some—infants, the elderly, people living with cancer or AIDS—are immunocompromised. Elderly adults often sicken on exposure to only a small fraction of the infectious dose that others require—an issue for the U.S. as it baby boomer population ages.

Just as an aging population poses a concern for public health, so too does an aging infrastructure pose a concern for water delivery. U.S. water infrastructure is outdated and deficient. In the next few decades, measures must be taken to reinforce or restore our water delivery pipes and systems, equipping them for both natural disasters and terrorist threats.

Drawing copied from the wall of an Egyptian pharaoh's tomb—dated to about 1450 B.C.—depicts an early method of water purification. One person, shown on right, pours water into the purifier, while another, shown on left, appears to use suction power to draw the water through a series of filters.

Once again the United Nations has declared a water decade: 2005 through 2015 will be the Water for Life Decade. Among the UN's Millennium Development Goals outlined for the decade are reducing the number of people worldwide who lack adequate water and sanitation by half. Additional efforts will concentrate on curbing the unsustainable exploitation of water. As with the UN's approach to increasing literacy, facilitating income generation, and curbing population growth, the focus will be on empowering women as a means of achieving its goals.

Certainly the goals are challenging. Achieving them will require cooperation among many stakeholders who are committed to expanding investments in water and wastewater infrastructure. New management strategies must embody conservation and efficiency for people everywhere, lest we find ourselves changing too slowly to quench the world's thirst. □

WHEN THE SEAS COME MARCHING IN

Hurricane Katrina exposed fatal flaws in the flood defenses of New Orleans. Those flaws remain.

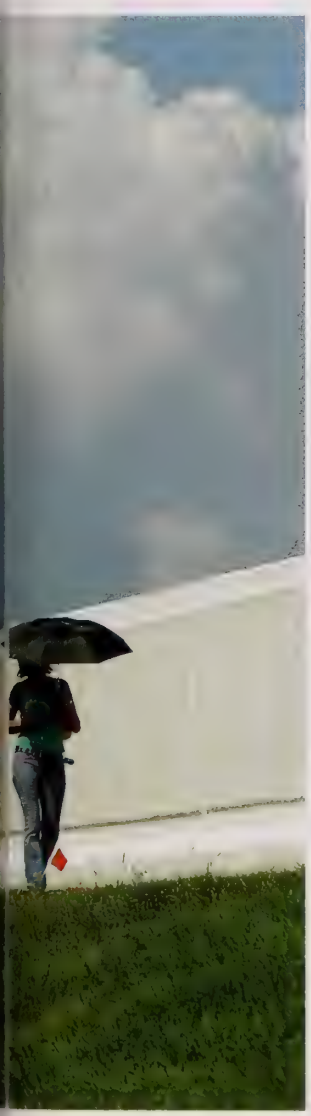
By Shea Penland

If you live in Louisiana and don't know how to swim, now might be a good time to learn.

—Shea Penland, "Taming the River to Let In the Sea," *Natural History,* February 2005

Less than seven months before hurricanes Katrina and Rita brought indescribable devastation and heartache to the Gulf coast, I warned the readers of this magazine, in the words quoted above, of the inevitable path toward destruction that New Orleans seemed determined to take. Of course, my near-term prescience was unintentional, but my advice is still sound: even if recent initiatives prove successful, you'll need at least a pair of waders. Since the hurricanes hit, committees have been formed, surveys have been commissioned, consciousness has been raised. Most of the attention has gone into investigating how the levees failed and how best to rebuild them, even though overambitious flood control was a prime cause of the conditions that made Katrina and Rita so deadly.

Hundreds of years of natural-resource exploitation and modifications to the flow of the Mississippi River—whose silty waters created the delta region of southern Louisiana—have cost the state more than 1,900 square miles of coastal wetlands in the twentieth century alone. The U.S. Geological Survey estimates that 213 square miles turned into open water between the fall of 2004 and the fall of 2005. Natural History *asked for my reassessment of the issues I raised from today's vantage point, two years after the hurricanes. Because so little had been done to address the underlying problems, it seemed apt to restate, in somewhat shorter compass, what I said at that time. My hope continues to be that someone will listen.*



Work continues on the floodgates of the 17th Street Canal levee. A breach in the levee flooded the Lakeview area of New Orleans with more than ten feet of water during the aftermath of Hurricane Katrina.

Every year the threat of hurricanes looms. The accompanying storm surges cause local, short-term flooding, but they also erode away parts of the coastal marshes and barrier islands that provide the only protection for the inhabited lowlands farther inland from the Gulf. Louisianans have focused on river flooding for hundreds of years, yet only in the mid-1970s did the state begin to take seriously the problem of coastal erosion.

Important as they are, though, beach erosion and flooding are still not the heart of Louisiana's problem. That, in a few words, is subsidence of the delta plain.

Before the levees were built to channel and "control" the Mississippi and other nearby rivers, floodwaters would spread out and slow down as they flowed over the delta. When the flow slowed, the river deposited its burden of silt, forming a new layer of earth. But the levees, which now constrict floods along a 1,200-mile corridor of the Mississippi, prevent the floodwaters from spreading across the delta. As a result, the river-borne silt is lost off the edge of the continental shelf.

The delta, primarily mud that had already filled the Mississippi River valley before the levees were built, is continuously being compacted under its own weight. As it compacts, it loses elevation, and without floods, no new sediments can arrive to build the land back up. In the past several hundred years, subsidence rates have ranged from one foot to four and a half feet per century.

Compounding the risk of catastrophic flooding is global climate change. Many climatologists expect such change to cause hurricanes even more frequent and more violent than those of the past several years. Sea levels are expected to rise by ten to twenty inches.

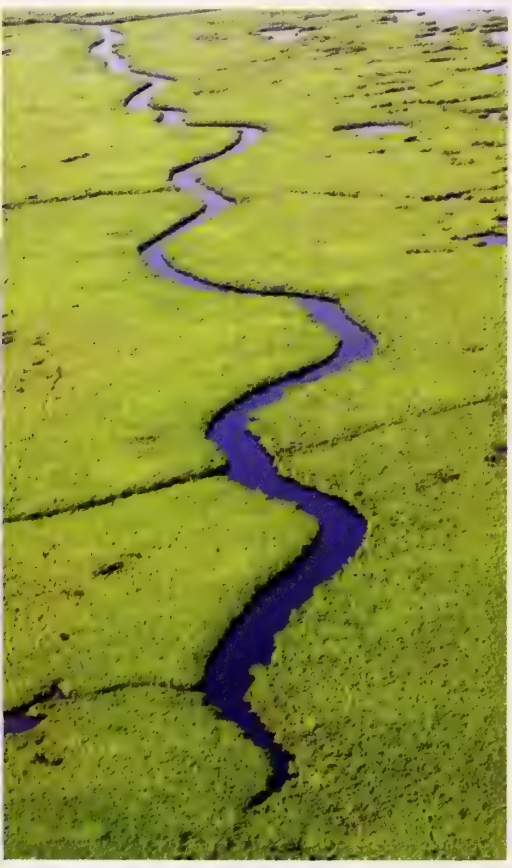
The threatened collapse of coastal Louisiana has been centuries, even millennia, in the making. Eighteen thousand years ago, toward the end of the last ice age, sea levels began to rise dramatically. For thousands of years the great glaciers that had formed in the preceding era melted into the ocean. Eventually, four thousand years ago, the sea level stabilized. But the Mississippi now met the sea in what had been its old valley. The river water, halted in its course by the Gulf of Mexico, no longer held sufficient energy to carry its sediment. Falling out of the flow, the sediment began to fill in the ancient river valley. The result was a subsidence-prone delta that could maintain its elevation only as long as sediment from upstream reached the delta plain each year.

Meanwhile, over the millennia, the Mississippi Delta has undergone a process known as delta-lobe switching. The path the river takes to the Gulf of Mexico is continually changing, because the river is continuously drawn along the most efficient path to the Gulf.

In the 1940s, in response to findings that the Mississippi was about to switch course again, the U.S. Army Corps of Engineers built a massive concrete structure known as the Old River Control Structure, at the confluence of the Red and Mississippi rivers, where the Atchafalaya begins. This structure controls the volume of water that flows down the Mississippi, allowing no more than 30 percent

of the flow to enter the Atchafalaya. The remaining 70 percent continues past Baton Rouge and New Orleans to the Mississippi's present delta in the Gulf. With the completion of the Old River Control Structure, the Mississippi River appeared tamed.

It was obvious even in the 1950s that the sediments created by the perennial spring floods were no longer reaching their natural resting grounds in levees, swamps, and marshes. At the time, that seemed a blessing. The primary effect, however, was to restrict sedimentary land buildup to two isolated locations on the coast: at Head of Passes, seventy miles southeast of New Orleans, where the Mississippi River reaches the Gulf, and at the Atchafalaya River outlets, south of Morgan City. Elsewhere across Louisiana, coastal land loss continued to worsen.



Wetlands in New Orleans. One restoration project, which has been operating since 1991, pumps freshwater into wetlands below New Orleans. The project is intended to mimic the natural over-bank flooding that built the delta in the first place. The project is a valuable model for restoration techniques, but it has had the unwanted effect of disrupting seafood harvesting.

But the downside of flood control is not limited to restricting the natural dispersal of sediments. It also interferes with the dispersal of nutrients across the delta. Even before the twentieth century, conservationists noted that alterations to the river were causing entire ecosystems to decline at some distance from the main stem of the river. Years after the levees and spillways were completed, investigators from the Louisiana Universities Marine Consortium discovered a "dead zone" of water spreading out into the Gulf of Mexico from the shoreline at the mouth of the Mississippi. At times it covered an area as large as New Jersey. Devoid of dissolved oxygen, the dead zone owed its existence to massive flows of fertilizers collected by the Mississippi and its tributaries.

Flood control and its multiple ramifications had set the stage for disaster.

In 1989, finally prodded into action, the Louisiana legislature established the Louisiana Wetlands Conservation Authority, and Congress subsequently passed the Coastal Wetlands Planning, Protection, and Restoration Act of 1990 (CWPPRA). By then, the total funding for various state and federal coastal restoration programs in Louisiana exceeded $50 million a year.

One of the first restorations was the Caernarvon Freshwater Diversion Project, which began operating in 1991. Planned prior to CWPPRA, the project called for discharging as many as 80,000 gallons of freshwater per second into the swamps, marshes, and shallow bays east of the Mississippi River and downstream from New Orleans, in Saint Bernard and Plaquemines parishes. The project consisted of a set of diversion gates built through the existing flood-control levees; the flow through the gates was intended to mimic the natural over-bank flooding that had built the delta in the first place.

Since 1991 the Caernarvon project has become a model that has afforded valuable practical experience with restoration techniques. It has also had unwanted effects. For example, the freshwater diversion project disrupted seafood harvesting by coastal communities, and as a result of lawsuits brought against the project, local oystermen have been awarded more than $1 billion in damages.

From 1991 until 1998, more than forty-five projects were begun under the auspices of the CWPPRA. But it soon became obvious to both state and federal governments that addressing coastal land loss in Louisiana far exceeded the scope of the original CWPPRA legislation. A new effort, known as Coast 2050, was set up to evaluate and plan for a larger-scale restoration of coastal Louisiana. That work resulted in a plan with an anticipated price of $14 billion. The Coast 2050 effort subsequently evolved into the Louisiana Coastal Area Ecosystem Restoration Project, or LCA, in which I participate as a geologist.

More than a hundred restoration projects are now active, but they are experimental, and their scale is such that even collectively they have relatively little impact on the fundamental problems. In the wake of the storms of 2005, however, public sentiment would support a more comprehensive effort to address coastal restoration.

There is no handbook on the subject. What we already know and what we are learning is contributing to the foundation of the emerging field of environmental restoration science. If we can apply the science fast enough, we may be able to keep Louisianans' homes and heads above water. The overriding lesson we've learned is the deadly hazard of playing around with rivers. □

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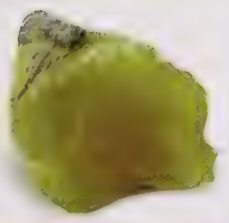

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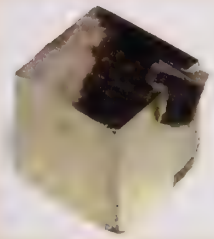

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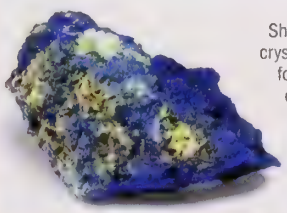

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Pipe directs rain from rooftop into cistern in "rooftop harvesting."

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Desalination cone placed over saltwater in the sun evaporates the water, which condenses on the cone's inner wall and trickles down into a collection channel around the bottom edge.

HYDRO TECH

Illustration by Chuck Carter

A wind-powered spray turbine mounted on an anchored platform in the ocean sucks water up through pipes, then filters and sprays it in fine droplets into the sky. The humidified air produces clouds and rain.

A bamboo treadle pump, made of inexpensive local materials, helps farmers tap groundwater to irrigate small plots of land.

The fine weave of women's old saris, folded four times, can filter out cholera-causing bacteria.

WATER AT WAR

Iraq's marshlands, once decimated by Saddam Hussein's campaign against his own people, are reviving with global aid.

By Azzam Alwash

When I was growing up in southern Iraq in the 1960s, my family used to take me on picnics to the Great Ziggurat temple and the royal burial grounds of Ur, about 140 miles northwest of the Persian Gulf. I remember the massive brick structures jutting up from a stark landscape, in contrast to my verdant hometown of Al-Hillah—once ancient Babylon—fed by the Euphrates River. Little did I know that my desert playground at Ur once sat on the shoreline of the Gulf, at the mouth of the Tigris and Euphrates rivers. The dry, ashen dirt where I played had been the center of a bountiful oasis where ancient kings had ruled and ancient priests had appeased their gods, a place that often bears the title "cradle of civilization": Mesopotamia.

Five thousand years ago the entire region was lush, fertile—an ideal birthplace for human civilization. Archeological studies published this year show that between 3000 B.C. and 2000 B.C. a concatenation of cities stretched eastward from Mesopotamia all the way to modern-day India and Pakistan. Yet the most extensive evidence of urban evolution comes from the old riverbanks of the Tigris and Euphrates. Solid wheels were used, and perhaps invented, there. Organized cultivation of wheat and barley began on those marshy shores. The cities' inhabitants developed a written language. And a distinct separation between state and temple was recorded.

By the time I was playing on the remnants of ancient Ur, many environmental changes had taken place. Droughts, changing river courses, and silting of the river outlets into the Gulf had pushed the coastline southward and the giant rivers eastward. Yet the Tigris and Euphrates were still infusing the land with life, a land said to have been the biblical Eden. In the 1970s 8,000 square miles of wetlands provided a home to hundreds of species of wildlife, as well as to people—the Marsh Arabs, or Ma'adan—whose ancestors had been thriving in the watery environment for centuries. Then the entire ecosystem crashed.

The region's worst environmental disaster in the history of human civilization took place in a single decade of my adult life. In the middle of the Iran-Iraq war, which lasted from 1980 until 1988, Saddam Hussein's regime began using water as a weapon, and a weapon of mass destruction at that. Supply roads were cut through the marshes, and large tracts were dried and then reflooded for strategic purposes, as Saddam's army blocked Iranian advances and hunted political enemies and weapons smugglers. But it was after the end of the first Gulf War in 1991, when the Ma'adan rose up with other Shi'a Iraqis against the regime (expecting U.S. help that never came), that the assault on the marshes began in earnest. Saddam Hussein's army dammed the rivers and dug extensive canals to divert the water and drive out the insurgents. The soldiers also contaminated the marshes with pesticides and pulsed high-voltage electricity through the water to kill whatever life might have remained.

Before 1990, the Tigris and Euphrates brought 25,000

Iraqi marshland scenes from the early 1970s (top row, from left to right): an elderly Ma'adan, or Marsh Arab, drinks tea; a Ma'adan village floats in open water; villagers collect reeds used for houses, fodder, and fuel; men in a motorboat tow two canoes. Present-day images mark the changes wrought by time, war, and restoration efforts (bottom row, from left to right): the Great Ziggurat in Ur sits far from the Persian Gulf; desiccated land lacks the wildlife once abundant there; a boy pilots a boat on a lush, reclaimed section of the Hawizeh Marsh; a mortar lies in dry dirt—a reminder of the work yet to be done.

billion gallons of water through Iraq each year. More than 60 percent of that flow came from the mountains of Kurdistan in spring, fed by melting snow. The low-lying marshes acted as a flood basin, annually refreshed with a large supply of freshwater that was laden with nutrients. The spring flooding of the marshes coincided with the spawning of several fishes and the end of winter dormancy for reeds, and ushered in the annual migration of more than 200 bird species between Siberia and Africa. The Basra reed warbler, the Dalmatian pelican, the Goliath heron, the grey hypocolius, the marbled teal—all thrived in the reedy haven, an ecosystem that lived by the annual pulse of fresh water.

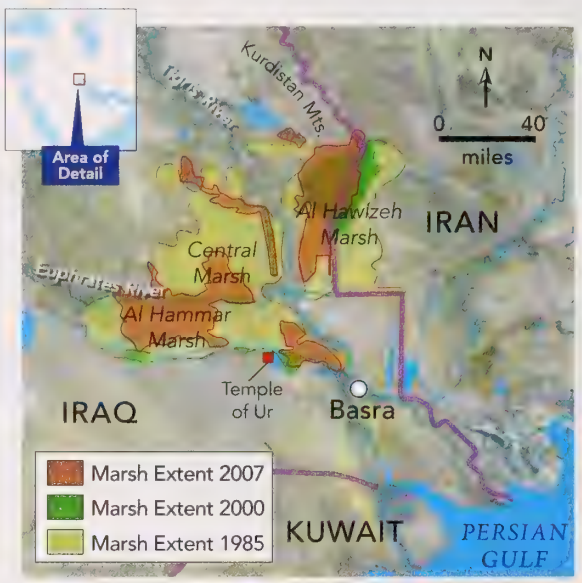
For millennia, people also relied on the regular influx. Sumerian farmers lived around the perimeter of the marshes and profited from the new layer of silt and clay swept in every year, which renewed the vitality of their farmland. Barley, wheat, and rice flourished in the long, moist growing season.

The marshes also provided the ancient Sumerians and some of their descendants—the Ma'adan—with plentiful fish and wildlife, not to mention an unusual source of construction material: reeds, particularly *Phragmites australis*. That species, which is treated as a pest in the United States, grows as high as thirteen feet tall. The Ma'adan cut and bound the reeds together to make huts and even islands atop the surrounding water. The reeds were fed to water buffalo and cattle, burned as fuel, bound into boats, and woven into mats. In more ways than one the reeds served as the scaffolding of the marshland. The thick reed growth helped to slow passing water and trap fine soil particles; some pollutants were absorbed and processed; organic matter built up and supported microscopic life, which in turn fed larger creatures. The overall effect was to turn the northern reaches

of the Persian Gulf into a haven for oysters and rich coral beds, on which the pearl divers of Kuwait made a living before oil was discovered. And before 1990—a turning point in Saddam's tightening control over the waterways of Iraq—more than half the fish consumed throughout the country came from the three main marshes in Iraq: Hammar, Central, and Hawizeh [*see map below*].

In 1991, when Saddam's forces were driven out of Kuwait, many Iraqi civilians revolted against their government but were defeated by the remnants of the Iraqi army. The rebels who could went into exile abroad, but the ones who couldn't went into the marshes with the Ma'adan. The watery world of the marshes provided food and easy shelter, and the soggy ground proved to be an insurmountable obstacle to the armored vehicles of the Iraqi army.

The marsh dwellers continued to harass the army units until Saddam decided to take drastic action against them. And so began an incredible engineering feat of destruction. Hundreds of miles of canals were dug to divert the waters of the Tigris and Euphrates away from the marshes, choking off their source of life. Acres upon acres of reeds were burned.



In just five years, the 8,000 square miles of Iraqi marshes were reduced to no more than 700 square miles along a sliver of the border between Iraq and Iran. Most of the rebels and the Ma'adan were forced to relocate to cities. There they were at the mercy of Saddam's regime, which had absolute power over rations and therefore over their survival. Yet the marsh was losing its ability to sustain life. Fisheries suffered as spawning grounds in the marshes dwindled; with the loss of reeds to filter the water, more algal red tides swept over the region, killing more wildlife; thousands of water buffalo succumbed to pesticide poisoning, and the Ma'adan sold many others before being relocated into settlements.

Yet the devastation, as far-reaching as it was, has proved to be reversible.

The few people who had stayed in the marshes began breaching dams and tearing down embankments in late March 2003 even before the fall of Baghdad. Thus began the restoration of the marshes. In the past few years, the wetlands have begun to flourish. Iraqis continue to breach embankments: three breakthroughs on the Euphrates made in March of this year will help restore flow to the Hammar Marsh. With foreign aid from around the world the marshes continue to grow.

Today, almost 3,000 square miles of the marshes are flooded. Half of that reflooded area seems to be in robust recovery; the other half still needs nursing. My colleagues and I have found encouraging numbers of endangered bird species—including Eurasian bittern, the Iraq babbler, pygmy cormorant, sacred ibis, and whiskered tern. The diversity of the wildlife improves daily.

One major problem, however, precludes the possibility of complete recovery: the loss of the seasonal freshwater pulses. Dams built in Turkey, Syria, and Iraq have, unfortunately, evened out the flow. Turkey began building its dams in the mountains of Kurdistan at the same time as the water was being diverted to dry the marshes. The so-called Southeastern Anatolia Project, which is nearly finished, will comprise more than twenty-two dams and nineteen hydroelectric plants. The dams, albeit beneficial to the economy of Turkey, stopped the freshwater pulses that drove the marshes' biodiversity.

If the flow continues at its current, sluggish rate, some species that depend on the annual flushing—particularly fishes—may not survive. Engineers working on the marsh restoration have devised a plan to replicate the pulses. The plan would direct water from the dam reservoirs into the marshes during late winter, when agricultural demand is minimized. The water would be held in the marshes into the spring season, regulated at the exit points and entrances to the marshes. Granted, such a scheme cannot truly replace the natural system, but the health of the marshes requires some kind of management, given that the dams upstream are likely to be in place for decades if not centuries to come.

The ultimate solution, of course, requires cooperation with upstream countries to coordinate seasonal releases of water for the benefit of the marshes. Some people, myself included, are hopeful. After all, five years ago most people shook their heads skeptically when they heard about the restoration of the Iraqi marshes; yet substantial progress has already been made.

The marshes are important not only for the health of the Gulf region, but also for their heritage as a rich cradle for both civilized and natural life. If more people and more countries step up to help Iraq, this rare ecosystem can be maintained for global benefit. All that is needed is political will. □

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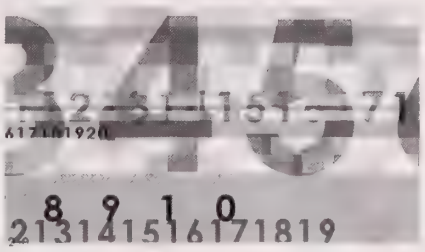

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Arthur T. Benjamin is Professor of Mathematics at Harvey Mudd College, where he has taught since 1989. He earned a Ph.D. in Mathematical Sciences from Johns Hopkins University. The Mathematical Association of America honored him with national awards for distinguished teaching in 1999 and 2000 and named him the George Pólya Lecturer for 2006–08.

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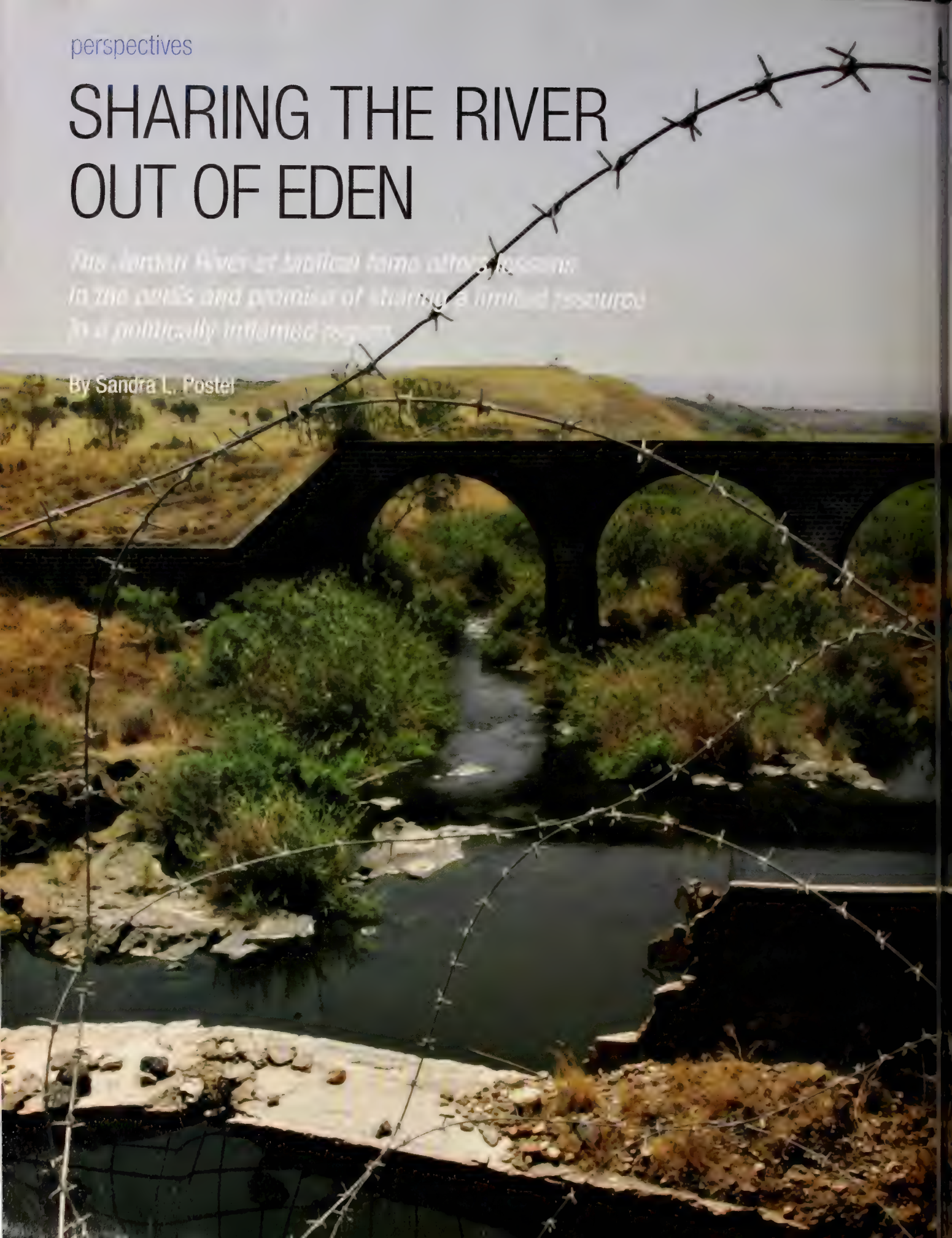
SHARING THE RIVER OUT OF EDEN

The Jordan River at Baptism Site Qasr al-Yahud in the West Bank is a symbol of hope and promise of sharing a limited resource in a politically inflamed region.

By Sandra L. Postel



When I first set eyes on the Jordan River, after a rainy winter in February 1992, I could scarcely believe that the thin ribbon of muddy liquid I saw winding its way southward could be the main prize in the contest for water in the Middle East. The Jordan is a small river. Its average annual flow is only 1.5 percent of what the Nile delivers to Egypt. By the time I encountered it, after several decades of its being dammed, diverted, and polluted, this legend of the biblical landscape, heralded in song as "deep and wide," appeared dirty and spent.

Rarely has such a modest river been asked to do so much for so many. The Jordan and its tributaries serve five distinct political entities: Israel, Jordan, Lebanon, the Palestinians, and Syria. And unsurprisingly—in this most contentious and water-scarce of places—there is still no agreement about how the blue gold should be shared among all the parties. The Palestinians in the West Bank and Gaza are chronically short of water, and use a quarter as much per capita as do the neighboring Israelis. Inequitable access fans the flames of tension. Meanwhile, downstream lies the fabled Dead Sea—the lowest-lying and saltiest lake on Earth, and the Jordan's final destination. But by the time the Jordan gets there, some 90 percent of its flow has already been diverted for domestic and agricultural uses upstream, so the river no longer sustains the sea. For the past quarter century, the lake level has been dropping about three feet a year; some warn that the Dead Sea could vanish by 2050.

As if those conditions weren't dire enough, climatologists warn that global warming and its attendant increases in drought and evaporation may intensify the water shortages in the Middle East. At the same time, the projected rise in sea level may expose the coastal aquifers of Israel and Gaza to ruinous invasions of saltwater, rendering ever more wells unfit to supply drinking water.

In many ways the water predicament in the Middle East seems as intractable as the decades-long feuds over territory, Jerusalem, and refugees. But is it really so unyielding? Are there untapped solutions waiting to be deployed? And could an equitable resolution of water disputes perhaps become the wedge that opens new pathways to the grail of peaceful coexistence?

As with so much in the Middle East, a little geography tells a lot of the story [*see map on following page*]. The Jordan owes its flow to the confluence of three streams—the Hasbani River, which originates in Lebanon; the Dan River in northernmost Israel; and the Baniyas River, which emerges from Syria. The Jordan then flows south about twenty-five miles to the Sea of Galilee, Israel's sole natural freshwater lake, which holds about a third of the nation's renewable water supply. About six miles south of the Sea of Galilee, the Jordan is joined by its main tributary, the Yarmuk River, which originates in Syria and forms the Syrian-Jordanian border before

Barbed wire runs along the Jordan River, which forms the northern border between Israel and Jordan. The two countries have diverted huge amounts of water from the river for domestic and agricultural uses. They've pumped wastewater into the river, particularly the sixty-five-mile stretch from the Sea of Galilee downstream to the Dead Sea, shown in part here.

merging with the Jordan River in Israel. The Jordan then continues its journey southward to the Dead Sea.

A source of water crossing so many political boundaries, especially given the overheated politics and thirsty terrain of the Middle East, is a recipe for tension. Political leaders have routinely threatened war over the control of water. Golda Meir warned in 1960, when she was the Israeli foreign minister, that any attempt by Arab nations to divert the northern tributaries of the Jordan would be "an outright attack on one of Israel's means of livelihood" and "a threat to peace." In 1990 Jordan's King Hussein declared that water was the only issue that could take him to war with Israel.

Ever since the creation of Israel in historic Palestine in 1948, the quest for water security among the parties of the Jordan basin has veered between unilateral action and cooperation. Recognizing the importance of water-sharing to the region's stability, in 1953 the U.S. president, Dwight D. Eisenhower, appointed Eric Johnston, chair of the International Development Advisory Board, as special ambassador to the region to help negotiate a water-development plan. After two years, the so-called Johnston formula emerged. It allocated water according to the amount and location of irrigable land that could receive surface water by gravity—a sensible approach that placed water "needs" above water "rights." By overlaying political boundaries on the map of irrigation potential, the Johnston plan arrived at a fair and technically feasible way of divvying up the water. Amazingly, the Johnston plan was acceptable to all parties at the time (though the Palestinians were not yet viewed as a distinct political entity). In the end, however, politics won out over rationality, and the plan was never formally ratified.

A spate of unilateral moves to capture and claim water followed, dramatically changing the hydrological landscape. In 1964 Israel began conveying the upper Jordan into its National Water Carrier, a system of canals and tunnels that supplies water to Tel Aviv and other coastal cities, as well as to desert agriculturalists in the Negev.

Attempts by the Arab nations to thwart Israel's diversion plans and capture the Jordan's headwaters for their own use led to skirmishes in the mid-1960s, including Israeli attacks on construction facilities at diversion sites in Syria.

It was Israel's military victories during the Six-Day War of June 1967, however, that sealed its strategic hydrologic advantage. None other than Ariel Sharon, an Israeli commander in that war, noted that "the Six-Day War really started on the day Israel decided to act against the diversion of the Jordan." Before the war, less than a tenth of the Jordan River watershed lay within Israel's borders; by the war's end, Israel had secured the vast majority of it. Israeli control extended to what had been Syria's Golan Heights (which drain into the Sea of Galilee) and Baniyas River, as well as to critical groundwater aquifers under the West Bank. The latter territory, previously the possession of Jordan, now provides Israel with about a third of its water.

The three underground aquifers of the West Bank figure centrally in any effort to delineate and constitute a Palestinian state. The Yarqon-Taninim aquifer, the largest, runs along the foothills of the West Bank and flows westward across the Green Line (the Israeli boundary before the 1967 war) toward the Mediterranean Sea. Israel can now tap this groundwater on either side of the Green Line, but the aquifer's main recharge zones lie under the West Bank.

During its occupation of the West Bank, Israel has prevented Palestinians from drilling wells for irrigation and has severely restricted Palestinian access to supplies. Journalist Fred Pearce reported in his 2006 book *When The Rivers Run Dry* that Palestinian families around Nablus spend between 20 and 40 percent of their income on water for drinking, cooking, and cleaning, while Israeli settlers nearby enjoy lawns and swimming pools.

This hydrologic inequity has worsened as a result of Israel's construction of the controversial separation barrier that it began building in 2002. Israeli military officials say

As elusive as it may seem, **water security**—a sine qua non for lasting peace in the region—**is within reach.**

the approximately 425-mile stretch of wall and fencing, which in many areas extends considerably east of the Green Line, is necessary to protect Israeli cities and towns from Palestinian suicide bombers, and that security concerns alone determine the barrier's route. The Palestinians dispute this, viewing the barrier instead as a land-and-water grab. According to the Applied Research Institute of Jerusalem (ARIJ), a nonprofit organization dedicated to protecting the Palestinians' natural resources, the barrier could ultimately isolate Palestinian villages from 134 wells and 62 springs, as well as from some 260,000 acres (about 405 square miles) of productive farmland.

Of course, the Palestinians themselves also bear some responsibility for their water predicament. Years of infighting between the two principal factions, Fatah and Hamas, have distracted officials from the basic needs of their people, a problem compounded by a severe lack of financial and technical resources.

Drip irrigation pipe in Netiv Ha'asara, Israel, rations out a precise sip of water to a plant. Israel and Jordan depend heavily on this technology for the efficient use of their limited water supply.

The water infrastructure is decaying, pollution is rampant, and the coastal aquifer is nearly destroyed. The water for 1.4 million Gazans comes from shallow groundwater that has long been overpumped—depleted faster than it can be replenished—and is already so contaminated by salt and pollutants that most of it does not meet the drinking-water standards of the World Health Organization.

As elusive as it may seem, water security for all—a sine qua non for lasting peace in the region—is within reach. Thanks to cooperation between scientists and citizen groups, advances in water-management technology, and agreements reached during peace talks in the early 1990s, there is a foundation on which to build lasting and more equitable water-sharing arrangements.

The Israeli-Jordanian peace treaty signed in October 1994, for instance, included water-sharing provisions that largely resolved the tensions between the two countries. Relying on the 1955 Johnston Plan to formulate his negotiating position, Jordan's lead water negotiator limited Israel's share of the Yarmuk River, critically important to his country's water security.

Nothing nearly as conclusive emerged from the Israeli-Palestinian talks culminating in the 1993 and 1995 Oslo Accords, though some progress was made. Because Jordan had disengaged from the Israeli-occupied West Bank in 1988, it was up to the Palestinians, then represented by the Palestine Liberation Organization, or PLO, to negotiate their own water deal with Israel. In the Taba Agreement, or Oslo II, signed by Israel and the PLO in September 1995, Israel formally recognized for the first time that the Palestinians have legitimate rights to West Bank groundwater—an important first step. How much water each side was entitled to, however, was left for the "final status" talks, which are yet to occur.

Coupled with further diplomatic initiatives to share water more equitably, a stronger push for straightforward measures to curb demand, expand supply, and use water more productively could generate enough water to satisfy the region's needs. And few countries have more technical know-how in water management than Israel does.

Half a century ago, Israeli engineers developed highly efficient drip irrigation methods, and they've been perfecting them ever since. Drip systems deliver water directly to the roots of plants at low volumes through perforated tubing installed on or below the soil surface. Drip systems nearly eliminate wasteful evaporation and runoff, and compared with more conventional irrigation, they can double or triple the crop yield per unit of water. Israel now applies drip and other micro-irrigation methods on two-thirds of its cropland. With the help of Israeli engineers, Jordan, too, has adopted those methods, and now applies them on 55 percent of its farmlands.

Israel has also moved aggressively to treat, recycle, and reuse its urban wastewater. Seventy-three percent of treated sewage from Tel Aviv and other cities gets used a

second time by farmers, in effect taking the "waste" out of wastewater. Recycled water makes up a fifth of Israel's total supply, and its share is projected to grow.

Despite such gains in efficiency, irrigated agriculture still accounts for about two-thirds of Israel's water use, yet it contributes only 2 percent to the nation's gross domestic product. Israel imports a good deal of its wheat and other staple foods, but it still irrigates substantial tracts planted with fruits, vegetables, and other high-return crops. By reducing agricultural water subsidies and paring back irrigated farming, Israel could free up a substantial quantity of water to share with its Palestinian neighbors—at little cost to its own economy.

Desalination—the removal of salt from seawater—could also yield sizable peace dividends. Although its costs are still high, they have fallen substantially in the past decade. In 2005, at Ashkelon, on the southern Mediterranean coast just north of Gaza, Israel opened the first of five planned desalination facilities. By a process called reverse osmosis, in which saltwater is filtered through a fine polymer membrane under high pressure to separate out the salts, the facility can produce 100 million cubic meters of desalinated water per year. That capacity makes the Ashkelon plant the largest reverse-osmosis seawater desalination plant in the world.

By 2010, Israel expects to be desalinating a total of 315 million cubic meters of seawater per year, nearly equal to its current use of freshwater from the West Bank aquifers. If Israel were to substitute desalinated seawater for West Bank groundwater, Palestinians there could double their current water use while easing up on the overpumping of the aquifers.

Unfortunately, no such deal is in the cards. Israeli officials have instead proposed that the United States help fund the construction of a desalination plant on the Mediterranean coast at Caesarea. From there, they suggest, the desalinated water could be transferred to the West Bank for use by the Palestinians. Under that proposal, Israel would retain its control of West Bank groundwater, and the Palestinians would get high-priced desalinated seawater from Israeli territory—hardly a recipe for Palestinian water security.

Why is Israel pushing for this approach? Driven by a deep mistrust of Palestinian motives, Israel feels a need to retain control over the region's water supplies. For their part, Palestinians publicly blame Israel's water greediness. Yet behind the scenes, even during the worst of the second intifada, ministers from both sides quietly met and agreed not to damage each other's water infrastructure.

Joined in destiny by the hydrological cycle, the people of the Jordan River basin know, whether consciously or subconsciously, that they must share the water of the basin and that cooperation can benefit them all. While traveling in the hills of Israel's western Galilee region in 1992, I visited an Arab village of 7,000 people called Kfar Manda. The sewage from the village was managed by a neighboring Jewish community, Yodfat. A series of small reservoirs stored Kfar Manda's wastewater and treated it biologically; it then became a source for drip irrigation in Yodfat's cotton fields. The Arab villagers got an inexpensive way of handling their sewage, which might otherwise have flowed untreated into their surroundings. And the Yodfat farmers got a reliable and less costly source of water for irrigation—water that carried enough nitrogen and phosphorus to markedly cut their fertilizer costs. By bridging the ethnic and religious divides, the two communities reaped benefits that neither would have achieved without the other.

Even during the worst of the second intifada, ministers from **both sides** quietly met and **agreed not to damage** each other's water infrastructure.

With similar methods and goals in mind, EcoPeace/Friends of the Earth Middle East (FoEME), a private organization of Arab and Israeli environmentalists, initiated the "Good Water Neighbors" project in 2001. It aims to organize joint water-management projects between cross-border communities in Israel, Jordan, and the Palestinian territories. Seventeen communities are participating so far, each one working with its partner across their common border on the water problems they share. A mayors' network has been formed to give residents a voice on such larger issues as the health of the Jordan River, the demise of the Dead Sea, and the implications of the separation wall under construction in the West Bank.

Along with the drip irrigation lines and desalination units that increasingly dot the landscape of the Jordan River basin, technical and civilian cooperation has persisted throughout years of violence and political stalemate. That spirit of cooperation stands ready to be harnessed and augmented to build a secure water future for all in the region. If it is not, political leaders will have squandered far more than water. □

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By Laurence A. Marschall

Industrial plants in River Rouge, Michigan, on the banks of the Detroit River

The Great Lakes Water Wars
by Peter Annin
Island Press; $25.95

When I was growing up in Buffalo, New York, the Great Lakes seemed to me to be a limitless source of water and of wealth. Ah, innocent youth! By the late 1950s the "Sweet Water Seas" to the west of town were turning foul, the freighters were docking less frequently, and the steel and auto plants were starting to close. Buffalonians like me, and our counterparts in other soon-to-be "rust belt" cities—Gary, Detroit, Cleveland, Erie—were beginning to lose their feeling of security and, in its place, to develop a new environmental anxiety.

In the decades since, state and local governments have learned to deal more effectively with sewage and industrial waste—"aided" in part by the continuing loss of heavy industry to other countries. The feeder rivers no longer catch fire, as the Cuyahoga did in downtown Cleveland in 1969, and pollution in the lakes has been reduced. But the 40 million people in the region who depend on Great Lakes water are still on edge, understandably worried about what the future will bring. Any threat to the integrity of Great Lakes water touches a raw nerve.

The greatest fear of the Great Lakes' terrestrial neighbors is that their waters will be stolen outright, diverted to irrigate golf courses in Las Vegas, fill swimming pools in Phoenix, and supply condos in San Diego. That's not sheer paranoia. The driest parts of the nation are also the fastest-growing. And over the years a number of elaborate proposals have been floated to get the Great Lakes flowing southwest.

One project of the 1960s, undoubtedly named the Great Recycling And Northern Development Canal so to create its grandiose acronym, called for freshwater to be pumped from the Hudson Bay watershed into Lake Huron, then through a series of canals to Montana and Wyoming, and eventually into the Colorado River. From there it would be distributed to nearby urban centers and agribusinesses. Public condemnation, and a price tag in the hundreds of billions of dollars, quickly squelched the idea, but it has never completely died.

Another flurry of worry erupted in

the 1970s over the decline of the Ogallala aquifer in the central United States, which supplies water to the High Plains. At the bidding of concerned plains-state legislators, the U.S. Army Corps of Engineers investigated the feasibility of transporting water to Kansas, Nebraska, and Colorado from what the Corps study euphemistically called "adjacent areas," sparking another heated reaction from the Great Lakes states.

Those episodes and others confirmed what was already pretty obvious: to the people in the eight states and two Canadian provinces that border the Great Lakes, the smallest diversion of water outside the watershed is to be vigilantly avoided. Even a trickle, they fear, would eventually open the floodgates of diversion and suck the lakes dry. Having seen the damage wreaked by mismanagement, they are not about to submit their lakes to the same fate as that of Russia's great Aral Sea [*see "Blue Planet Blues," by Eleanor J. Sterling on page 29*].

Peter Annin, a former correspondent for *Newsweek*, describes the environmental and legislative turmoil that engulfs the Great Lakes today. Since the 1980s, the states and provinces bordering the Great Lakes have enacted a series of protocols and agreements on water management that have met with varying degrees of success in preventing unsound diversions. But water-management difficulties stem not merely from outside threats, but also from the challenge of defining and reconciling the often clashing interests of multiple governments, residents, and industrial communities in the waters they each claim but must share. The Great Lakes drainage does not respect political boundaries.

Case in point: Waukesha, Wisconsin, a western neighbor and now suburb of Milwaukee, wants to replace its current system of wells with a connection to the bigger city's water mains, which draw from Lake Michigan. The proposal looks like a straightforward matter of plumbing. Yet Waukesha's effluent goes into the nearby Fox River, which drains into the Mississippi—not into the Great Lakes—so even the simple joining of pipes represents a diversion with international repercussions.

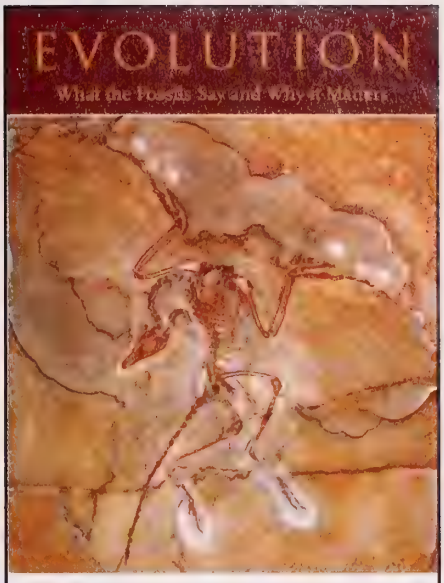
Does that seem far-fetched? Shouldn't tap water for a bedroom community remain a matter for local politicians, particularly in a region as rich in water as the Great Lakes? Perhaps, but Waukesha and the other cases Annin recounts are emblematic of one of the central issues of our century, as population growth, expanding economies, and limited resources bring the water wars to everyone's doorstep.

Dry: Life Without Water
edited by Ehsan Masood and Daniel Schaffer
Harvard University Press; $29.95

Most of us who read this magazine (or write for it, for that matter) scarcely have to think about where our next glass of water is coming from: it's just a matter of turning a tap. Yet for roughly a billion people, dwellers in the arid and semi-arid regions that make up 40 percent of the Earth's landmasses, every drop is a serious concern. Because water is so critical to economic development, arid lands are among the poorest places on Earth—with the notable exceptions of Las Vegas, Dubai, and other highly subsidized anomalies of the developed world.

Desert lands, not surprisingly, are also among the most threatened ecologically, because the delicate balance of their scanty resources is so readily upset. *Dry,* a collection of short vignettes about life in some of the planet's most arid places, written by scientists and science journalists and illustrated with vivid photography, describes a recent attempt to address the economic and environmental problems of those lands. The chapters report on a variety of practices, identified by a multiyear scientific program, that both utilize and conserve the water resources and biodiversity of the developing world.

Some of the practices are straight-



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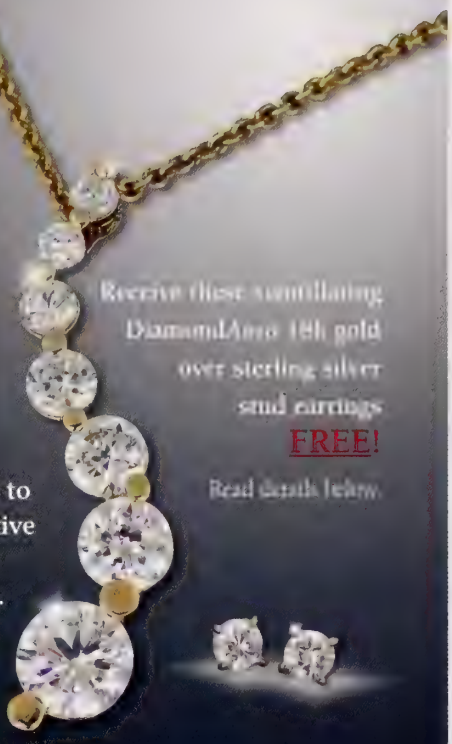

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forward applications of modern technology to traditional settings. In the northwestern provinces of China, for instance, rural villages have long collected the seasonal rains of summer and autumn in communal "rain cellars" for use during the rest of the year. But traditionally the cellar walls have been made of raw clay, so by the end of the dry season the remaining water is often muddy and contaminated. In recent years a project known as "Mother's Water Cellars" has financed 80,000 cement-lined cisterns in those rural areas, providing longer-term, healthier storage of a scarce resource. "Now we can wash our faces at any time we want," said one satisfied farmer.

Even drier conditions call for higher-tech solutions. Villages in Chile's Atacama Desert, where years can pass without significant rainfall, have survived for the most part on water trucked in from far away. But in the late 1980s Chilean scientists began to experiment with large nets made of polypropylene mesh, which catch droplets of fog and channel them into plastic pipes for distribution [*see "Hydro Tech," on pages 54–55*]. A square meter of net can catch perhaps ten liters of water a day; a system of such fog catchers can easily provide water for a village of several hundred people at little operating cost. A trial project in the 1990s met with great initial success.

Unfortunately, local residents and government officials let the system fall into disrepair. By 2000, villages that had been getting reliable water from the nets were back to trucking it in. That setback may be nothing more than a minor stumble on the path to self-sufficiency. Perhaps given more durable webbing, and economic incentives for locals to maintain the nets and piping, Chile's fog nets could become a permanent source of water in the years to come.

Many sustainable water-saving tactics recognized in *Dry* are traditional systems that have been around for centuries. In the Jebel Akhdar mountains of Oman, the parched hillsides

support a flourishing rose-growing industry, irrigated by a complex system of tunnels and covered, stone-lined channels that date back thousands of years. And in the date-producing Ziz Valley in Morocco's High Atlas mountains, women pass along traditional knowledge about how best to irrigate fields, how to select the best seeds for planting, and what times are best to plant and harvest for greatest yields.

What works in the arid world, according to the reports in *Dry*—what seems to keep traditional societies in parched lands both healthy and productive at a modest level—is a combination of ancient methods and appropriate new technologies. None of the places highlighted in the book seem destined to become the next Las Vegas or Dubai—but who would wish for *that*?

Sacred Sea: A Journey to Lake Baikal
by Peter Thomson
Oxford University Press; $29.95

Siberia's Lake Baikal, like so much that is Russian, is riddled with contradictions. Halfway between the Urals and the Pacific, the lake is so remote that few Russians have seen its shores, even though they regard it with a mystic reverence far surpassing the American devotion to Yellowstone or the Grand Canyon. As for non-Russians, few foreigners appreciate Baikal's uniqueness—if they know of its existence at all. Yet Baikal surely ranks among the greatest natural wonders of the world. Its crescent-shaped basin, though outranked in surface area by Lake Superior and a few other bodies of water, is far deeper and far greater in capacity than any other lake: Baikal, by itself, holds a fifth all the freshwater on Earth.

Formed 25 million years ago, the "blue eye of Siberia" is thousands of times older than the Great Lakes. And because Baikal is so isolated, a kind of watery analogue to Australia or New Zealand, its aquatic ecosystem has evolved in unique directions. Among more than twenty-five species of fish that live exclusively in the lake, the most abundant are weird creatures called golomyankas, whose bodies are translucent. No more than a foot long, they swim with their heads up, like seahorses, and bear their young live. The lake is even home to a singular species of mammal, the nerpa, the world's only freshwater seal, which can spend as long as three-quarters of an hour in the frigid depths before coming up for air.

What makes Baikal even more remarkable is the purity of its water. No

Nerpas, freshwater seals, lounge on Lake Baikal's shore.

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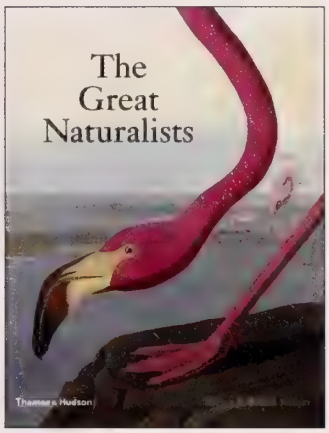

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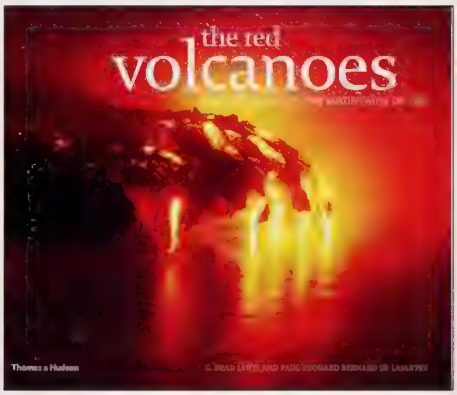

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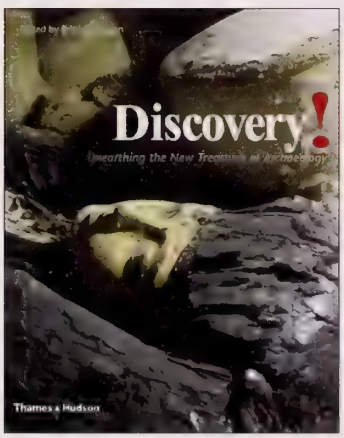

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cities abut the lake, only a few towns with low-five-figure populations, and the only roads of note, along with the Trans-Siberian Railway line, lie along the far southern end. Scarcely 80,000 people make their homes along the 1,200 miles of shoreline, most in tiny settlements accessible only by boat. The only major sources of pollution come from a pulp and paper mill on the southern shore, and from effluent dumped into inflowing rivers by cities and farms in Siberia and Mongolia. At first glance, the world's greatest lake seems an astonishingly pristine and untroubled place.

Peter Thomson, the founding editor and producer of National Public Radio's ecology news show *Living On Earth,* made his first trip to Baikal in 2000. In part, his goal was to find out for himself whether the Edenic character of Baikal was fact or myth. His account of that journey is a hybrid of environmental reporting and personal travelogue, the product of a six-month respite Thomson took after his marriage ended and his mother died. Casual readers will enjoy his accounts of meandering across the Pacific on a container ship with his younger brother, camping among Siberian aspens, and feasting on reindeer meat under the northern lights. But the focal points of his narrative are Thomson's vivid encounters with activists, scientists, and residents of the Baikal region. Just how pristine was the lake, he asked them, and how likely was it to remain that way?

The answer, it turns out, is as murky as Baikal's waters are clear. Baikalian optimists view the lake as a self-cleaning ecosystem, constantly filtered by tiny shrimplike crustaceans called *Epischura baicalensis.* According to one local scientist, those zooplankton, endemic to Baikal, "consume every molecule of any substance that comes to its waters," making it impossible to overload the lake with pollutants. Others, equally eloquent, see glowering clouds on the horizon. They reasonably fear increased development, swelling amounts of effluent from distant cities, insufficient preservation of the national reserves and parklands along Baikal's shore, and the disruption of Baikal's ecosystem by global warming.

Whether the optimists or the pessimists are right, they do agree on one thing: the choices made and actions taken in the coming century will determine whether or not Baikal will remain one of Mother Russia's most timeless treasures.

Laurence A. Marschall, author of The Supernova Story, *is W.K.T. Sahm Professor of Physics at Gettysburg College in Pennsylvania and director of Project CLEA, which produces widely used simulation software for education in astronomy.*

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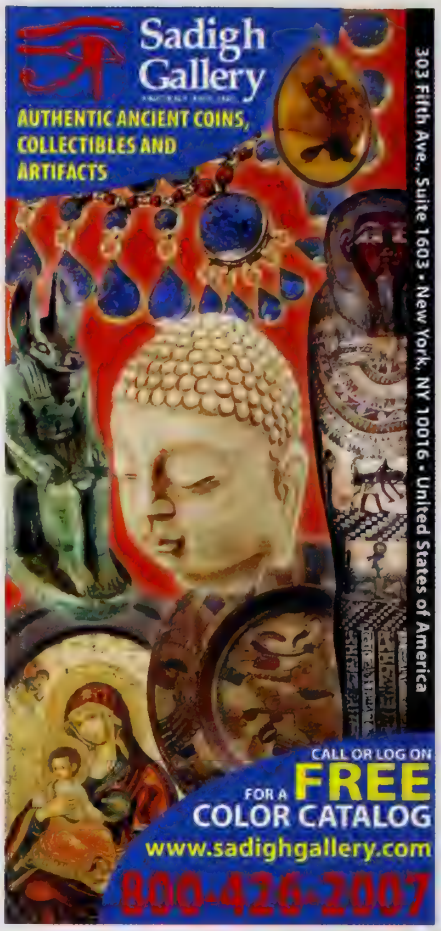
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At the Museum

AMERICAN MUSEUM & NATURAL HISTORY

www.amnh.org

Immerse Yourself *Water: H2O = Life*

Anyone who's ever watched kids running through sprinklers or splashing around with toys in a tub knows the mesmerizing hold water has on children. So when the American Museum of Natural History set about designing the exhibition *Water: H2O = Life*, awareness of this fascination helped transform compelling yet complex science into a family affair.

From hands-on water works to interactive computer stations to evocative walk-throughs, visitors young and old are treated to a host of viscerally engaging experiences as they explore a virtual "flood" of information about the essential nature of water and the current and future water-related challenges facing the world.

"This eye-opening exhibition brings visitors closer to water in more ways than they ever imagined possible and hopefully leaves them with a deep sense of responsibility towards conservation of this remarkable ingredient for life," said Eleanor Sterling, Director of the Museum's Center for Biodiversity and Conservation and curator of *Water*, which opened this month.

Setting an interactive tone from the start is a veil of mist through which visitors pass at the entrance, a reminder of the abundance of a substance that covers more than two-thirds of the Earth's surface. Striking a paradoxical note, the next display evokes potable water's rarity—less than 1 percent of the planet's water is readily available for human use—with water droplets falling from the ceiling to a table so that people can run their hands beneath the drops.

And this is just the beginning.

An interactive feature on the three states of water allows visitors to touch water as a liquid, ice, or vapor, while a display nearby explains the water cycle, the series of stages by which our finite water supply endlessly moves from underground and bodies of water into the atmosphere and back again. (Part of the inspiration for this exhibition was the finding in a 2006 AMNH survey that 41 percent of U.S. residents could not name a single component of the water cycle, such as evaporation or rain.)

Other hands-on exhibits permit visitors to block and release the flow of water, akin to building and removing a dam, to study the respective effects on a river bed; pump water from an artesian well to mark the decrease of water pressure in another well drawing from the same underground source; and lift a container filled with water to get a sense of its weight and the literal burden that carrying water still is for many populations around the globe. This last is accompanied by a beautiful and telling display of water receptacles from ancient vessels to plastic cans used today. Of related and special interest to children, a working tabletop model of a PlayPump water system shows how children playing on a merry-go-round are actually pumping water from the ground into a tank, an ingenious method that has

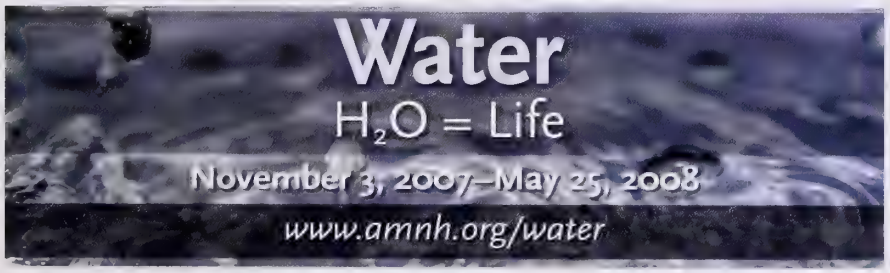
greatly increased access to clean drinking water in rural communities of Africa.

A microscope station allows visitors to see the world of microbes in a single drop of untreated water, while what is seen through the eyepiece is projected on a large screen. One drop of water from a lake, river, or ocean can contain thousands of tiny organisms, like algae, protozoans, bacteria and viruses. (Most are harmless—fewer than 1 percent of bacteria cause disease.)

Throughout the exhibition, live animals, models, fossils, and taxidermy specimens embody the varied and surprising adaptations animals have evolved to survive in extremes of wet and arid conditions. Visitors will learn, for example, how wood frogs freeze to hibernate in winter; Pompeii worms survive plumes of near-boiling water on the Pacific floor; and albatrosses, which spend months flying or floating on the ocean, drink water too salty for most birds and land animals. A vivarium of live mudskippers offers a look at curious "fin-footed" fish that can live for extended periods out of water. Beneath a model polar bear on a faux ice floe, younger children are drawn to a matching game in which blocks, when properly aligned, trigger videos about life where ice is the norm.

Also making dry statistics real is an interactive quiz testing visitors' "H2O IQ" with such questions as how much water it takes to make a T-shirt or a hamburger, an exercise that's fun, informative, and surprising. In fact, anyone visiting *Water* isn't likely to soon forget that nearly 900 gallons of water are needed to produce just 2.2 pounds of rice!

Early in the exhibition, visitors pass through a re-creation of a water-sculpted slot canyon, a graphic portrayal of the power of water to shape the contours of the planet. The human effect on the landscape is starkly represented near the end of the exhibition with a haunting, life-size, walk-through diorama of Mono Lake and its once-submerged tufa (or limestone) towers, exposed when the water level dropped some 45 feet over decades of diverting fresh water to Los Angeles. On the brink of collapse in the late 1970s, Mono Lake's ecosystem is now on the mend through efforts by the state of California, spurred on by graduate students and concerned citizens—a message of hope that human action can also act as a healing force.



Water: H2O = Life is organized by the American Museum of Natural History, New York (www.amnh.org), and Science Museum of Minnesota (www.smm.org) in collaboration with Great Lakes Science Center, Cleveland; The Field Museum, Chicago; Instituto Sangari, São Paulo, Brazil; National Museum of Australia, Canberra; Royal Ontario Museum, Toronto, Canada; San Diego Natural History Museum; and Singapore Science Centre with PUB Singapore.

The American Museum of Natural History gratefully acknowledges the TAMARIND FOUNDATION for its leadership support of *Water: H2O = Life*, and the Johns Hopkins Center for a Livable Future for its assistance. *Water: H2O = Life* is supported by a generous grant from the NATIONAL SCIENCE FOUNDATION. Exclusive corporate sponsorship for *Water: H2O = Life* is provided by JP MORGAN. The Museum also extends its gratitude to the Panta Rhea Foundation, Park Foundation, and Wege Foundation for their support of the exhibition's educational programming and materials.

Science on a Sphere: The "Globe" Theater

If you've ever longed to see Earth from space, now is your chance—with Science on a Sphere, a spectacular feature at the heart of the new exhibition *Water: H2O = Life*.

In this exhibit, a six-foot-diameter globe hangs suspended as if floating, depicting in living color how water defines and drives the planet. The stunningly realistic effect, showing shifting conditions on a seemingly rotating orb, is achieved by four full-motion video projectors, placed at the four corners of the room and controlled by a central computer, beaming images derived from data gathered by NASA satellites and other scientific sources.

In one sequence, Earth's surface, of which nearly 71 percent is covered in water, is contrasted with frozen Mars and hot, dry Venus, as well as with the Moon, which is waterless. Through time-lapse projections, Earth's water cycle springs to life as tropical areas turn green, then brown; ocean currents move warm water from the tropics to polar regions and cold polar water toward the tropics; and snow cover comes and goes.

Even deep beneath Earth's surface, water in minerals that make up Earth's mantle is seen to be on the move, making possible the movement of continents, and causing volcanoes, earthquakes, and the rise of new mountain ranges. Science on a Sphere presents patterns of water and population distribution, and graphically shows how little water is suitable for fresh human use.

Science on a Sphere is an amazing educational tool for both kids and adults. Dynamic and realistic visual interpretations of actual scientific data illuminate Earth's systems and ask us to think about how and why Earth is changing before our very eyes.

Science on a Sphere (SOS) is the creation of the Global Systems Division, Earth System Research Laboratory of the National Oceanic and Atmospheric Administration (NOAA). Support for SOS is provided by the National Science Foundation and NOAA with technical assistance from the Scientific Visualization Studio at NASA Goddard Space Flight Center

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Museum Events

AMERICAN MUSEUM & NATURAL HISTORY

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EXHIBITIONS

The Butterfly Conservatory
Through May 26, 2008
Mingle with up to 500 live, free-flying tropical butterflies in an enclosed habitat. Learn about the butterfly life cycle, defense mechanisms, evolution, and conservation.

H. DAVIES/AMNH

These pupae will soon be butterflies.

Mythic Creatures: Dragons, Unicorns, and Mermaids
Through January 6, 2008
Mythic Creatures traces the origins of legendary beings of land, sea, and air. Cultural artifacts bring to light surprising similarities—and differences—in the ways peoples around the world have depicted these beings, and fossil specimens suggest a physical basis for the many forms they have taken.

Mythic Creatures: Dragons, Unicorns, and Mermaids is organized by the American Museum of Natural History, New York (www.amnh. org), in collaboration with The Field Museum, Chicago; Canadian Museum of Civilization, Gatineau; Australian National Maritime Museum, Sydney; and Fernbank Museum of Natural History, Atlanta. *Mythic Creatures* is proudly supported by **MetLife Foundation**.

Undersea Oasis: Coral Reef Communities
Through January 13, 2008
Brilliant color photographs capture the dazzling invertebrate life that flourishes on coral reefs.

Beyond
Through April 6, 2008
Exquisite images from unmanned space probes take visitors on a journey through the alien and varied terrain of our planetary neighbors.

The presentation of both *Undersea Oasis* and *Beyond* at the American Museum of Natural History is made possible by the generosity of the Arthur Ross Foundation.

Unknown Audubons: Mammals of North America
Through January 6, 2008
The stately Audubon Gallery showcases gorgeously detailed depictions of North American mammals by John James Audubon, best known for his bird paintings.

Major funding for this exhibition has been provided by the Lila Wallace-Reader's Digest Endowment Fund.

Exoplanets and the Search for Life
Through March 2008
Two striking astronomical instruments demonstrate the need for extremely specialized tools in the search for planets around stars other than our own Sun.

This exhibit, part of the education and public outreach efforts of NASA's Navigator Program, was made possible through a grant from NASA's Michelson Science Center at the California Institute of Technology.

GLOBAL WEEKENDS

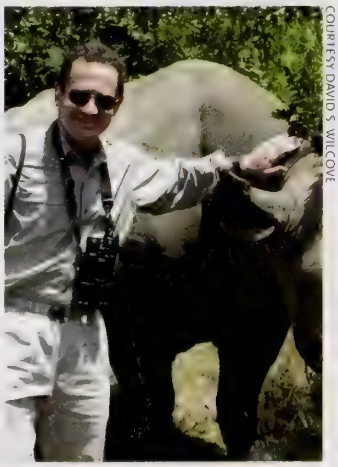
Buddhist Ritual Song and Dance from Korea
Friday, 11/2, 7:00 p.m.
The Young San Preservation Group performs.

City That Drinks the Mountain Sky
Sunday, 11/18, 2:00 p.m.
Arm-of-the-Sea Theater tells the story of New York City's water supply through puppetry, poetry, and music.

Global Weekends are made possible, in part, by The Coca-Cola Company, the City of New York, the New York City Council, and the New York City Department of Cultural Affairs. Additional support has been provided by the May and Samuel Rudin Family Foundation, Inc., the Tolan Family, and the family of Frederick H. Leonhardt.

LECTURES

No Way Home
Tuesday, 11/13, 7:00 p.m.
David S. Wilcove explores animal migration and the dangers our current environment presents for the successful growth of species that migrate.



COURTESY DAVID S. WILCOVE

Adventures in the Global Kitchen: An Evening with Jay McInerney
Tuesday, 11/13, 7:00 p.m.
Jay McInerney will share stories of viniculture and offer tastings of favorite wines. A book signing follows.

Life in the Valley of Death
Tuesday, 11/20, 7:00 p.m.
Alan Rabinowitz discusses the largest tiger reserve in Myanmar.

Our 100-Million-Year-Old Ecosystem
Wednesday, 11/28, 6:30 p.m.
Michael Novacek will discuss Earth's 100-million-year-old evolutionary history and ways to protect its future.

FILM

Margaret Mead Film & Video Festival
Friday–Sunday, 11/9–11

ROSE CENTER FOR EARTH AND SPACE

Sets at 6:00 and 7:30 p.m.

Friday, 11/2

Visit www.amnh.org for lineup.

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www.amnh.org/mead

WORKSHOPS

Introduction to Human Origins
Three Thursdays, 11/1–15
6:30–8:00 p.m.
Use hominid casts to learn about morphological analysis and how scientists reconstruct behavior from fossil evidence.

FAMILY AND CHILDREN'S PROGRAMS

Field Trip to the Moon
Every Wednesday, 10:30 a.m.
Guided by a live presenter, this new program flies visitors to the Moon in the Hayden Planetarium.

Flint-knapping Demonstration
Saturday, 11/17, 12:30–1:30 p.m.
With anthropologist John Shea.

Dr. Nebula's Laboratory: Life with Lucy
Saturday, 11/17, 2:00–3:00 p.m.
(Recommended for families with children ages 4 and up)
Help Dr. Nebula's apprentice, Scooter, travel back in time to meet our hominid ancestors.

This program is made possible, in part, by an anonymous donor.

NASA/ESA/ESO/WOLFRAM FREUDLING ET AL. (STECF)

Artist's conception of a primordial quasar

Public programs are made possible, in part, by the Rita and Frits Markus Fund for Public Understanding of Science.

HAYDEN PLANETARIUM PROGRAMS

TUESDAYS IN THE DOME

Virtual Universe
Why the Universe Looks the Way It Does
Tuesday, 11/6, 6:30 p.m.

Celestial Highlights
Here Comes Mars!
Tuesday, 11/27, 6:30 p.m.

HAYDEN PLANETARIUM SHOWS

Cosmic Collisions
Journey into deep space to explore the hypersonic impacts that drive the formation of our universe. Narrated by Robert Redford.

Cosmic Collisions was developed in collaboration with the Denver Museum of Nature & Science; GOTO, Inc., Tokyo, Japan; and the Shanghai Science and Technology Museum.Made possible through the generous support of CIT. *Cosmic Collisions* was created by the American Museum of Natural History with the major support and partnership of the National Aeronautics and Space Administration's Science Mission Directorate, Heliophysics Division.

Sonic Vision
Fridays and Saturdays, 7:30 and 8:30 p.m.
Hypnotic visuals and rhythms take viewers on a ride through fantastical dreamspace.

Presented in association with MTV2 and in collaboration with renowned artist Moby.

IMAX MOVIES

Dinosaurs Alive!
On location with AMNH scientists past and present, this stunning new large-format film uses scientifically accurate, computer-generated images to bring to life these intriguing animals, from the earliest dinosaurs of the Triassic Period to the creatures of the Cretaceous.

LATE NIGHT DANCE PARTY

One Step Beyond
Friday, 11/30, 9:00 p.m.–1:00 a.m.
This monthly party in the Rose Center features the biggest names in techno, electronica, and jazz. Food and drink keep the party going.

INFORMATION

Call 212-769-5100 or visit www.amnh.org.

TICKETS AND REGISTRATION

Call 212-769-5200, Monday–Friday, 9:00 a.m.–5:00 p.m., and Saturday, 10:00 a.m.–4:00 p.m., or visit www.amnh.org. A service charge may apply. All programs are subject to change.

AMNH eNotes delivers the latest information on Museum programs and events to you monthly via email. Visit www.amnh.org to sign up today!

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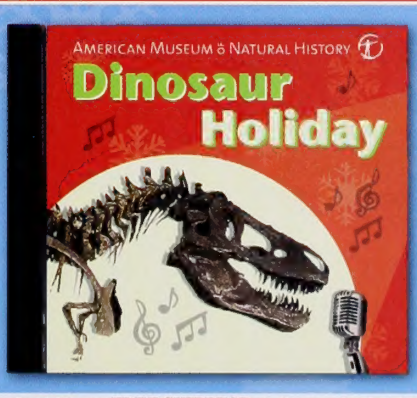

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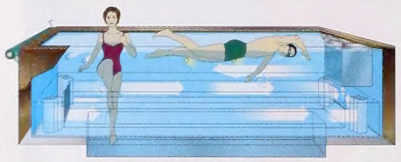

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THE SKY IN NOVEMBER

By Joe Rao

Mercury becomes easy to see with the naked eye in the morning sky early this month; for northern observers, this apparition is its most favorable one of the year. The planet starts the month rising more than an hour before sunup, far below and to the left of Venus, and shining a bit brighter than the nearby first-magnitude star Spica. Mercury remains within four degrees to the left of Spica for the first week of the month. From the 1st through the 11th the planet's brightness increases fourfold, helping to make the second week of the month Mercury's finest show. It rises an hour and a half before sunrise and several minutes before the onset of morning twilight, in a totally dark sky. On the 7th a lovely waning crescent Moon appears to ride well above and to the right of Mercury and Spica. The following morning Mercury approaches its greatest western elongation, nineteen degrees from the Sun. Thereafter it slowly turns back toward the Sun, but it should remain visible low in the east-southeast about forty-five minutes before sunrise until the 22nd.

Venus dazzles in the predawn morning sky, rising almost four hours before sunrise at the start of the month. It loses only about ten minutes to the Sun by month's end, and is well up in the southeast sky by sunrise all month. Viewed through a telescope, Venus starts the month resembling a half Moon (a phase called dichotomy), but after a week it gradually becomes more gibbous. A crescent Moon lies to the right of Venus on the morning of the 5th.

Mars becomes a noteworthy evening object this month, advancing its rising time from about three and a half hours after sunset when the month begins to about two hours by month's end. It reaches opposition this year on Christmas Eve, and as that event draws near, the planet's brilliance almost doubles, from magnitude −0.6 to −1.3. By late in the month, many holiday shoppers who cast a casual glance skyward will wonder about the identity of that lustrous, pumpkin-hued "star" low in the east-northeast sky.

Jupiter bids evening skywatchers a fond, albeit slow, adieu. At the start of the month it lies low in the southwest during the chilly dusk, setting a little more than two hours after sundown. By the 20th it sets before the end of evening twilight.

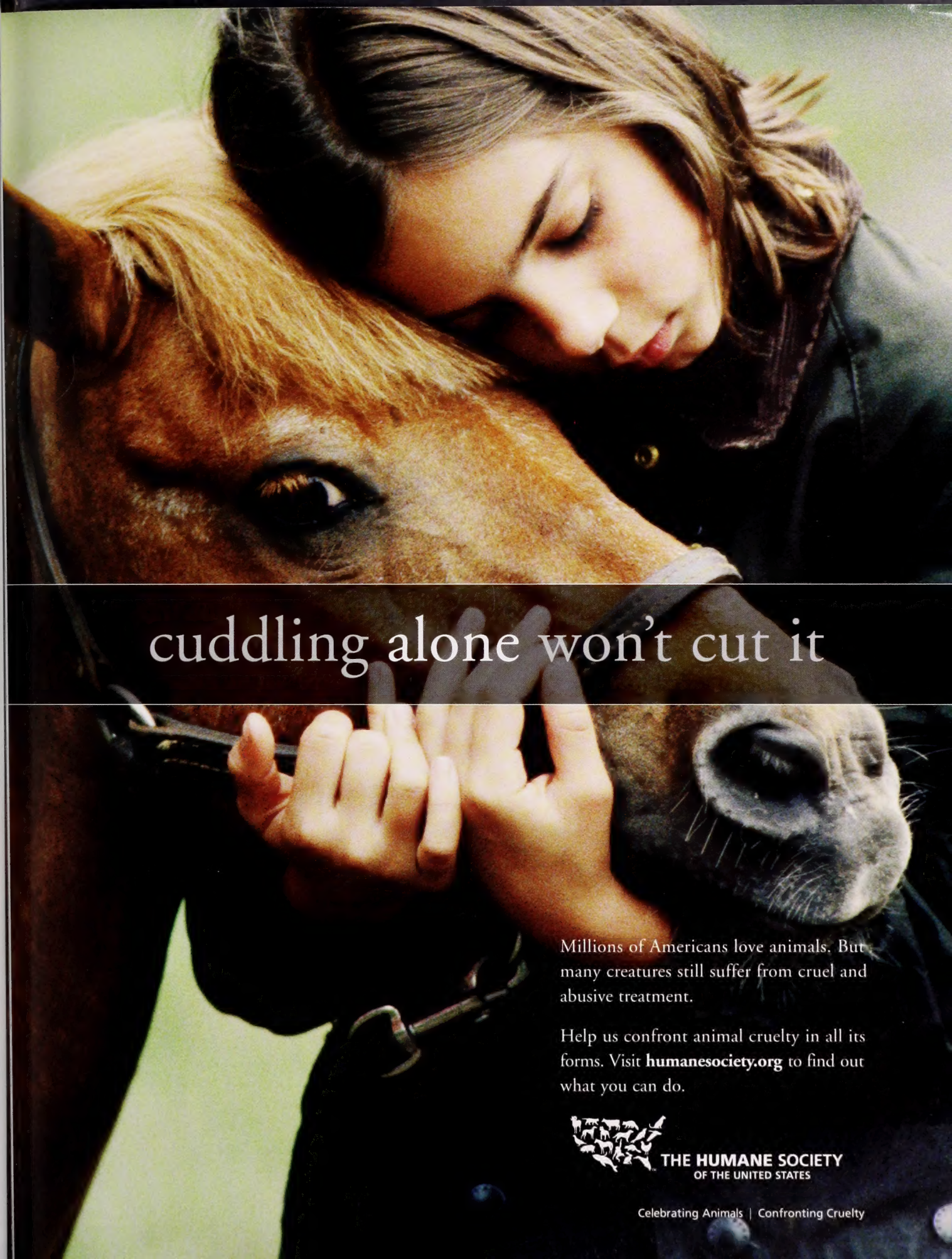
Saturn begins the month seven degrees east of the bluish star Regulus, in the constellation Leo, the lion, and moves a degree farther east of the star by month's end. The planet rises more than five hours before sunrise on the 1st, at about local midnight by the 20th, and before 11:30 P.M. by the 30th. By then the planet is high in the south-southeast as morning twilight begins. At magnitude +0.8, Saturn outshines Regulus (magnitude +1.4), but the planet is at its faintest since 1997.

The Moon is at last quarter on the 1st at 5:18 P.M. (eastern daylight time) and wanes to new on the 9th at 6:03 P.M. Our satellite waxes to first quarter on the 17th at 5:32 P.M. and to full on the 24th at 9:30 A.M.

An occultation of Regulus, the brightest star in Leo, takes place before sunrise on the morning of the 3rd, when a fat waning crescent Moon passes in front of the star. The event is visible chiefly in the southern United States, Mexico, and the Caribbean; over parts of Georgia, Florida, and Alabama it takes place during morning twilight or right after sunup. The star disappears behind the Moon's bright limb, then dramatically reappears about an hour later from behind the Moon's dark limb. Visit tinyurl.com/274cer for a list of viewing times for more than a hundred cities.

Standard time returns on Sunday the 4th. Set your clocks back one hour.

Unless otherwise noted, all times are eastern standard time.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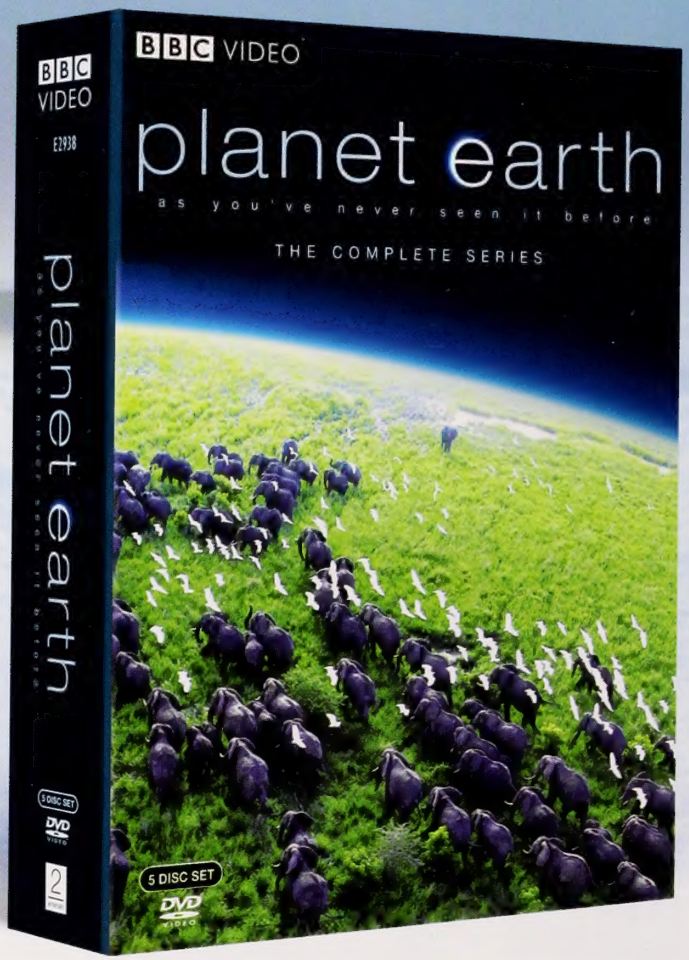

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